USAID
FROM THE AMERICAN PEOPLE

Global Water for Sustainability
PROGRAM

Environmental Flow Recommendations for Reserve Flows in the Mara River,

Kenya and Tanzania

FIU
Florida International University
Miami's public research university

Transboundary Water for Biodiversity and Human Health in the Mara River Basin Program, Kenya & Tanzania (TWB-MRB)

Environmental Flow Recommendations
for Reserve Flows in the Mara River,
Kenya and Tanzania

This publication was funded by the people of the United States through the Agency for International Development (USAID) within the framework of the Transboundary Water for Biodiversity and Human Health in the Mara River Basin Program, Kenya & Tanzania (TWB-MRB). The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Agency for International Development of the Unites States Government.

Global Water for Sustainability Program
Florida International University
Biscayne Bay Campus
3000 NE 151 St. ACI-267
North Miami, FL 33181
USA
Email: glows@fiu.edu Website:
www.globalwaters.net

For bibliographic purposes, this document should be cited as:

GLOWS – FIU. 2012. Environmental Flow Recommendations for the Mara River, Kenya and Tanzania. Global Water for Sustainability program (GLOWS). Miami, FL

Table of Contents

List of Appendices

List of Acronyms

ASPT	Average Score Per Taxon
BBM	Building Block Methodology
EFA	Environmental Flow Assessment
EFR	Environmental Flow Recommendation
EIS	Ecological Importance and Sensitivity
EMC	Ecological Management Category
FIU	Florida International University
FDC	Flow Duration Curve
GLOWS	Global Water for Sustainability
LVBC	Lake Victoria Basin Commission
LVBWO	Lake Victoria Basin Water Office
LVSCMA	Lake Victoria South Catchment Management Authority
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
MOWI	Ministry of Water and Irrigation
NGO	Non-Governmental Organization
PES	Present Ecological State
PHABSIM	Physical Habitat Simulation Model
SASS	South African Scoring System
USAID-EA	United States Agency for International Development – East Africa
WRMA	Water Resources Management Authority
WRUA	Water Resource User's Association
WSL	Water Surface Level
WWF-ESARPO	Worldwide Fund for Nature – Eastern and Southern Africa Regional Programme Office

List of Tables

List of Figures

List of Images

Executive Summary

Both the Kenyan and Tanzanian national water policies and laws call for protection of a reserve in all aquatic ecosystems (GoK 2002, 2007; URT 2002, 2009). The reserve is generally defined as the minimum water levels that must be left in the system in order to sustain, as a first priority, basic human needs and aquatic ecosystems. These policies and laws recognize that healthy river systems require minimum flow levels to be sustained, but that rivers in turn provide a multitude of ecosystem services for communities, including clean drinking water, food, building materials, and religious and cultural roles.

Environmental Flow Assessments (EFAs) have become the scientifically accepted way of determining minimum flow levels needed to sustain healthy rivers. EFAs are structured, science-based approaches that combine hydrological information about a river system with social, physical and biological indicators to determine the minimum sustainable flow levels needed to maintain all components of the river ecosystem. EFAs recognize that rivers have natural periods of both high and low flows, and that these variations play important roles in river ecosystem functioning and thus should be protected as components of the reserve.

In 2006, the Transboundary Water for Biodiversity and Human Health in the Mara River Basin (TWB-MRB) project, implemented under the Global Water for Sustainability Program (GLOWS) with funding from the U.S. Agency for International Development (USAID), began the process of developing an EFA for the Mara River Basin, Kenya and Tanzania. This undertaking was a collaborative effort between Florida International University (FIU) and WWF Eastern and Southern Africa Regional Programme Office (WWF-ESARPO), and it was done in partnership with the Lake Victoria Basin Commission (LVBC) of the East African Community, Kenyan and Tanzanian water resource managers, regional and international scientists, and other stakeholders in the basin.

The Mara River, a trans-boundary river shared between Kenya and Tanzania, was selected as the site for this effort due to the tremendous social, biological and economic value the river has for both countries, as well as the current threats facing the river and the people and ecosystems that rely upon it. Deforestation, over-grazing by livestock, unregulated extraction of water and untreated inputs of sewage and solid waste all threaten the quantity and quality of water provided by the Mara River, which are critical to maintaining all the other ecosystem services upon which people and wildlife in the basin rely. Currently, the Mara is still flowing and in good condition, which makes this an opportune time to put in place measures to ensure this state into the future.

The EFA process for the Mara River began in 2006 and consisted of several phases: an assessment of key sites in the upper and middle reaches of the basin, additional surveys in the upper and middle reaches during critical low flow periods to determine the sufficiency of preliminary EFA recommendations, and assessment of key sites in the lower portion of the basin. This present EFA report for the Mara River Basin represents a synthesis of the past six years of work conducted in the Mara River Basin, and presents major findings and environmental flow recommendations from all phases of EFA work for the entire Mara River Basin, Kenya and Tanzania.

The Building Block Methodology (BBM) was applied in determining environmental flows for the Mara River. This method involves a team of specialists comprised of a social scientist, hydrologist, hydraulics engineer, fluvial geomorphologist, water quality specialist, riparian vegetation specialist, fish specialist, and macroinvertebrate specialist. This team selected representative sites in distinct reaches of the basin; surveyed social, physical and biological characteristics of the river as a function of flow levels; and evaluated their dynamics during low and high flow events. The scientists relied on critical indicators to suggest minimum sustainable flow levels for each component of the river ecosystem during different "building blocks" of the river's hydrograph. Flow recommendations were made for both drought years, when flows are needed to just sustain river function at base levels, and for maintenance years, when normal river processes should be occurring. The final EFA prescription is a modified flow regime on a month by month basis that can be presented as a set of flow targets for water resource managers.

This EFA found that there is sufficient water in the Mara River during years of normal rainfall to allow for some water extraction throughout the year at all sites. At Site 1 on the Amala River, the recommended Reserve flow levels account for 28% of mean annual runoff during maintenance years. At Site 3 on the border between Kenya – Tanzania and the Masai Mara National Reserve – Serengeti National Park, the Reserve accounts for 45% of mean annual runoff. At Site 5, the reserve accounts for an average of 42% of mean annual runoff. It is important to note, however, that the percent of flow held in the reserve varies over the course of a year, mirroring the natural highs and lows of the system. The majority of water available for abstraction is therefore concentrated in the months when flows are highest.

During drought years, the situation is quite different. Recommended reserve flows exceed the historical average flows for three months at Site 1, two months at Site 2, and one month at Sites 3-5, and they leave little water available for extraction during the remaining months, particularly at Sites 1 and 3. The observation that recommended drought year reserve flows leave little water available, particularly in the upper and middle reaches of the Mara, may be the first clear evidence of a trend toward unacceptable alterations of the Mara River's flow regime. There could be several explanations for the difference between environmental flow recommendations and average drought year flows. First, determination of environmental flows should be an ongoing process that relies on the cautionary principle to protect sufficient minimum flows; however, continued monitoring could reveal that required reserve levels are lower than prescribed here. Second, the prescribed reserve levels could prove to be accurate, but levels of extraction could be unsustainably high during dry seasons of drought years and need to be reduced. Third, prescribed reserve levels could be accurate and abstraction levels could be reasonable, but land-use practices in the basin may have sufficiently altered the hydrograph of the river such that dry season drought year low flows are unnaturally low, suggesting that land rehabilitation in the upper catchment is necessary for the reserve to be restored.

This EFA did not take into account the water needs of the Mara Wetland, which may be different. Additional surveys should be done in that critical ecosystem to ensure sufficient reserve flows are available to maintain its ecosystem function. This EFA is also a living document that should be updated as needed as the river continues to be monitored and determinations are made if sufficient water quantity and quality is being provided to maintain desired ecosystem services.

In order to implement the findings of this EFA and to protect reserve flows in the Mara River Basin, several key recommendations were proposed: 1) use EFA recommendations to determine allowable water extraction permit levels; 2) monitor discharge and extraction levels in the river in order to reduce extractions if the reserve is threatened; 3) develop small-scale, off-catchment storage capacity to capture high flows for use during low flow periods; 4) develop capacity of both water resource managers and community Water Resource User's Associations (KE) and Water User's Associations (TZ) to monitor and protect reserve flows; 5) decrease land degradation, particularly in riparian areas, to promote natural water storage and maintain higher flows in dry seasons.

The recommendations of this EFA have been adopted and recommended for implementation by the Lake Victoria Basin Council of Ministers of the East African Community. This document represents a tremendous effort on the part of many concerned stakeholders to protect and provide for a healthy, flowing Mara River. As one of the first trans-boundary EFAs to be completed and adopted by a regional governing body, the Mara River EFA has already been a tremendous success. However, the true measure of its success will take place on the ground, over the scale of many years to come, as the Mara River continues to provide a functioning ecosystem, to the equal benefit of both the people and natural ecosystems that depend upon it.

Introduction

Reserve Flows and Environmental Flow Assessments

Both the Kenyan and Tanzanian national water policies and laws call for protection of a reserve in all aquatic ecosystems (GoK 2002, 2007; URT 2002, 2009). The reserve is generally defined as the minimum water levels that must be left in the system in order to sustain, as a first priority, basic human needs and aquatic ecosystems (Figure 1). These policies and laws recognize that healthy river systems require minimum flow levels to be sustained, but that rivers in turn provide a multitude of ecosystem services for communities, including clean drinking water, food, building materials, and religious and cultural roles. Many rivers are now being adversely impacted by deforestation and other land cover changes, poor agricultural practices, unregulated extractions and unmitigated pollution, threatening their capacity to provide sufficient quantity and quality of water for both humans and ecosystems. Ensuring protection of a sufficient reserve is one of the most critical steps needed to ensure the long-term health and viability of river systems into the future.

Environmental Flow Assessments (EFAs) have become the scientifically accepted way of determining minimum flow levels needed to sustain healthy rivers. EFAs are structured, science-based approaches that combine hydrological information about a river system with social, physical and biological indicators to determine the minimum sustainable flow levels needed to maintain all components of the river ecosystem. EFAs recognize that rivers have natural periods of both high and low flows, and that these variations play important roles in river ecosystem functioning and thus should be protected as components of the reserve. More than 200 different methodologies have been applied worldwide in determining environmental flows (Tharme 2003), trending in recent years towards those approaches that consider water needs of ecosystems in a 'holistic' or multidisciplinary framework. At the opposite end of the EFA spectrum, another approach to determining reserve flows is to protect only those flow levels that are exceeded 95% of the time according to a daily flow duration curve, a value also known as Q95. Although Q95 flows occur naturally at times, usually during dry seasons of drought years, these flow levels are insufficient to sustain all the components and processes of a healthy river ecosystem over time. Thus, in river systems in which more detailed information is available or can be attained, EFAs represent a further development in the process of determining and protecting sufficient reserve flows for riverine ecosystems.

In 2006, the Transboundary Water for Biodiversity and Human Health in the Mara River Basin (TWB-MRB) project, implemented under the Global Water for Sustainability Program (GLOWS) with funding from the U.S. Agency for International Development (USAID), began the process of developing an EFA for the Mara River Basin, Kenya and Tanzania. This undertaking was a collaborative effort between Florida International University (FIU) and WWF Eastern and Southern Africa Regional Programme

Office (WWF-ESARPO), and it was done in partnership with the Lake Victoria Basin Commission of the East African Community, Kenyan and Tanzanian water resource managers, regional and international scientists, and other stakeholders in the basin. The Mara River, a trans-boundary river shared between Kenya and Tanzania, was selected as the site for this effort due to the tremendous social, biological and economic value the river has for both countries, as well as the current threats facing the river and the people and ecosystems that rely upon it.

Figure 1: Regional laws support protection of reserve flows

Both Kenya and Tanzania have passed legislation aimed towards ensuring access to safe water resources for all people, as well as sustaining the valuable ecosystems upon which these people depend. The principle of environmental flows is evident in the wording of these laws.

Kenya Water Resources Management Act (2002)
Defines the "reserve, in relation to a water source, [as] that quantity and quality of water required (a) to satisfy basic human needs for all people who are or may be supplied from the water resource; and (b) to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the water resource." The Water Act further states that "the Minister, the Authority and all public bodies shall, when exercising any statutory power or performing any statutory function in relation to the water resource concerned, take into account and give effect to the requirements of the reserve (Part III, 13 (3))."

Draft versions of the new Kenya Water Resources Management Act include very similar wording in regards to determination and protection of the reserve.

Kenya Water Resources Management Rules (2007)
Calls for the Authority to establish the reserve based on a) Water resource records and reserve water demand, or b) 1) ecological vulnerability, 2) human vulnerability, 3) local observations of historic drought flows, 4) maintenance of perennial flows, and 5) consultations with WUAs.

Tanzania National Water Policy (2002)
Recognizes the importance of environmental flows and prioritizes water use such that "Water for basic human needs in adequate quantity and acceptable quality will receive highest priority. Water for the environment to protect the eco-systems that underpin our water resources, now and in the future will attain second priority and will be reserved (Section 4.1.2)."

Tanzania Water Resources Management Act (2009)
Defines the reserve as "the quantity and quality of water required for (a) satisfying basic human needs... and (b) protecting aquatic ecosystems" and states that "the Minister shall...determine the reserve for the whole or part of each water resource which has been classified...and the Minister, the National Water Board, Basin Water Boards and all public bodies shall, when exercising any statutory power or performing any statutory duty, take into account and give effect to the requirements of the reserve (Section 37, 1-3)."

The Mara River

The Mara River begins in the Napuiyapui Swamp of Kenya, where an average of 1,400 mm of rain every year maintains seeps and springs that feed the Mara's main tributaries—the Amala and the Nyangores—as they flow through the Mau Forest. However, rapid deforestation in this region in recent decades has resulted in 32% loss of forest cover, leading to faster runoff of rainwater and greater rates of erosion (Mati et al. 2008, Defersha and Melesse 2011, Defersha and Melesse 2012), which have in turn led to changes in the hydrological regime of the upper tributaries, including higher and flashier floods and lower and more prolonged low flows (Mango et al. 2011a, 2011b). As the rivers leave the Mau Forest, they flow through areas densely populated by small-scale settlements. In this region, the Amala and Nyangores provide a primary water resource for local communities, particularly during the dry seasons, but they are also increasingly impacted by degradation of riparian forests through cultivation and livestock watering, increasing rates of extraction for irrigation, and development of urban centres that lack sufficient facilities for sewage treatment or solid waste disposal.

The two tributaries join to form the Mara River in a more arid region in which annual rainfall is below 1,000 mm. Here, the Mara becomes the only permanent source of flowing water, providing a critical resource for the pastoralist Maasai community for watering of livestock and for wildlife inhabiting the surrounding grasslands. However, high densities of livestock and resulting over-grazing on this fragile land have led to declines in grassland cover, bringing rapid runoff and high sediment loads into the river

(Dutton 2012). Additionally, poorly regulated development of tourism facilities in the region, particularly along the riverbanks, has increased inputs of often untreated sewage directly into the river. Downstream of this region, the Mara enters the world-famous protected areas of the Masai Mara National Reserve in Kenya and the Serengeti National Park in Tanzania. Here, the river sustains one of the wonders of the natural world—the largest remaining overland migration of over one million wildebeest, zebras and other ungulates, who rely on the Mara as the only perennial water source in the region. Due to strong reliance of the migration on the river, some studies have suggested that significant declines in the quantity and quality of water in the river could result in a crash of the wildebeest population and the entire Serengeti ecosystem (Gereta et al. 2009). The quality of water in this region is strongly influenced by flow level, likely due to the huge effect of large wildlife upon the river such as hippopotamus, further emphasizing the importance of maintaining sufficient flows in the channel (GLOWS 2011).

Downstream of the protected areas, the river flows through a region of small-scale cultivation and livestock keeping in which hundreds of thousands of people depend upon the river as their primary water source, particularly in the dry season. However, the river also supports small- and large-scale mining operations in this region, which utilize heavy metals in processing materials near the riverbanks, as well as increasing levels of extraction for irrigation. The river flows downstream from here into the expansive Mara Wetland, which plays an important role in filtering the river water before it enters Lake Victoria and supports a number of fishing communities who live along it. Although the wetland provides a variety of ecosystem services for these communities, it also occasionally threatens them and their livelihoods by flooding and expanding into settlements and cultivated areas nearby. Expanse of the wetland has been suggested to be caused by increased rates of sediment deposition from upstream reaches, although this link is still untested (Mati et al. 2008).

Throughout the entire basin, the Mara is a living resource, providing a variety of resources, but also impacted by the use of these resources in ways that could eventually threaten the very resources the river is able to provide. Maintaining sufficient quantity and quality of water in the river is the key to maintaining all the other ecosystem services upon which people and wildlife in the basin rely. Currently, the Mara is still flowing and in good condition, which makes this the perfect time to put in place measures to ensure this state into the future.

EFA Report

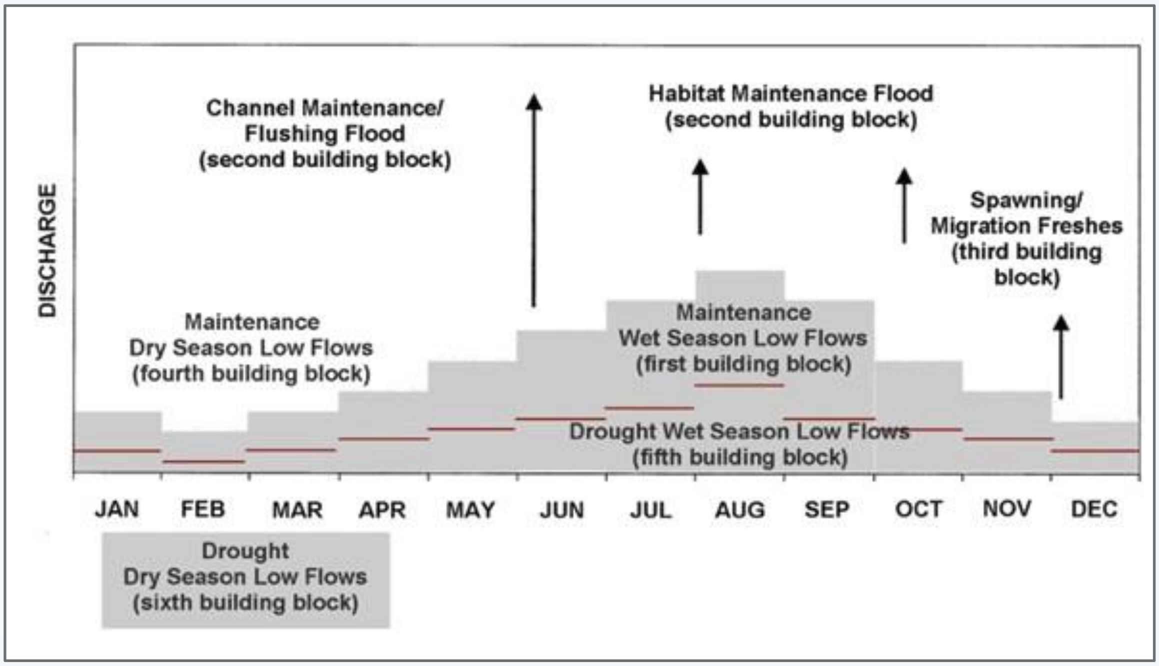
The EFA process for the Mara River began in 2006 with an assessment of key sites in the upper and middle reaches of the basin. The findings from this first phase of the EFA were summarized in a report which was adopted in 2009 by the Lake Victoria Basin Council of Ministers (LVBC 2010). Recommendations from that first assessment led to additional surveys done in the upper and middle reaches during critical low flow periods and at finer temporal and spatial scales in the upper and middle portions of the catchment. The primary goal of these studies was to determine the sufficiency of preliminary EFA recommendations for the upper and middle portions of the catchment and to suggest any necessary refinements (GLOWS 2011). The first assessment also recommended that field sampling and EFA recommendations be extended into Tanzania, and this work was undertaken in 2011-12, as the second phase of the EFA. This present EFA report for the Mara River Basin represents a synthesis of the past six years of work conducted in the Mara River Basin, and presents major findings and environmental flow recommendations from all phases of EFA work for the entire Mara River Basin, Kenya and Tanzania.

The EFA recommendations for the Mara River that are presented in this document were developed through the survey of five sites distributed throughout distinct geomorphological regions in the basin that were surveyed during low and high flows, as well as a subset of sites that were surveyed on a twice monthly basis over the course of a year. This detailed field data was combined with literature research and discussions with scientists, resource managers, local communities and other stakeholders to produce a consensus of minimum flow recommendations required to sustain the health of the Mara River. The recommendations of this EFA have been adopted and recommended for implementation by the Lake Victoria Basin Council of Ministers of the East African Community. This document represents a tremendous effort on the part of many concerned stakeholders to protect and provide for a healthy, flowing Mara River. As one of the first trans-boundary EFAs to be completed and adopted by a regional governing body, the Mara River EFA has already been a tremendous success. However, the true measure of its success will take place on the ground, over the scale of many years to come, as the Mara River continues to provide a functioning ecosystem, to the equal benefit of both the people and natural ecosystems that depend upon it.

Objectives and Methods

An initial workshop was conducted in 2006 to bring together EFA specialists, resource managers and stakeholders in the region to discuss the development of the EFA for the Mara River. During this workshop, the Mara EFA team elected to use the Building Block Methodology (BBM), which is widely used in Africa and provides reliable environmental flow recommendations with minimum data requirements (King et al. 2000). Two of the primary advantages of the BBM are 1) it recognizes the importance of a variable flow regime and 2) it prescribes quantitative flow targets for different periods of the year. Rivers are very dynamic systems, and both low and high flows, and even floods and droughts, play important roles in their ecological function. Each of these hydrological features is considered a "building block," which makes up the river's hydrograph (Figure 2). A summary of the ecological processes maintained by each building block can be found in Appendix 1.

Figure 2: River Building Blocks classify the most critical elements of the flow regime needed to maintain physical and biological processes



The BBM method first brought together a team of specialists comprised of a social scientist, hydrologist, hydraulics engineer, fluvial geomorphologist, water quality specialist, riparian vegetation specialist, fish specialist, and macroinvertebrate specialist. See Appendix 2.

This team selected representative sites in distinct reaches of the basin; surveyed social, physical and biological characteristics of the river as a function of flow levels; and evaluated their dynamics during low and high flow events. The scientists relied on critical indicators to suggest minimum sustainable flow levels for each component of the river ecosystem during base flow conditions (during dry months), maintenance flow conditions (during wet months) and floods (which may occur several times a year). Flow recommendations were made for both drought years, when flows are needed to just sustain river function at base levels, and for maintenance years, when normal river processes should be occurring. The team then collaborated to reach a consensus about flow levels that will maintain the river ecosystem at the desired ecological management category. Flow recommendations can be made either to maintain a river at its current ecological state or improve it to a less impaired state. Flow recommendations were then extrapolated over an entire hydrological year, following the shape of the river's natural hydrograph. The final EFA prescription is a modified flow regime on a month by month basis that can be presented as a set of flow targets for water resource managers.

Figure 3: Critical indicators used to determine a river's natural flow regime and ecological health

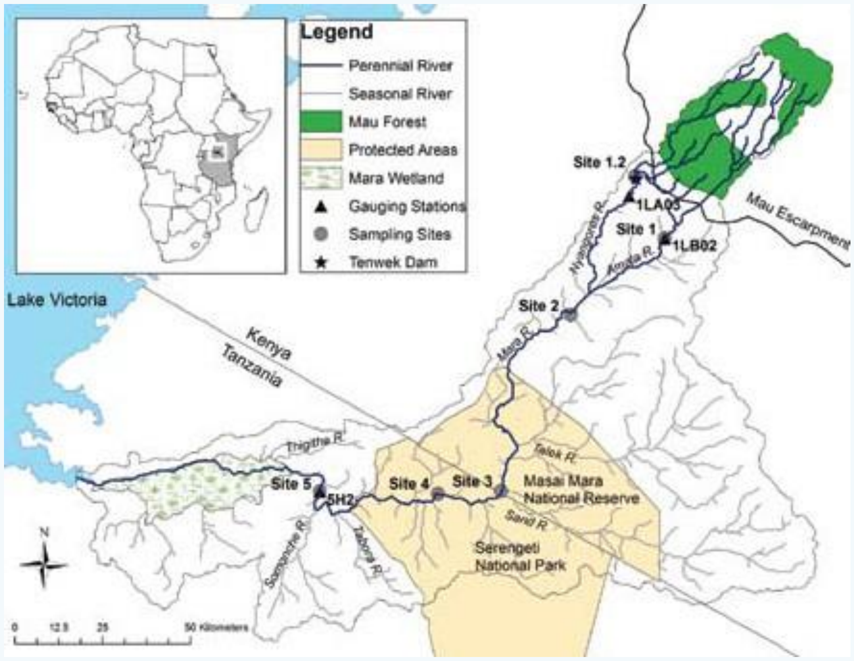
1. Functioning of natural sediment generation processes
    a. Presence of stable river banks
    b. Intact riparian zones
    c. Absence of large-scale erosion denuding landscapes
    d. Absence of excessive fine-scale sediment deposition in river channel
2. Occurrence of a variety of instream and riparian habitats to provide habitat for diverse species
    a. Adequate distribution of pools, runs and riffles
    b. Presence of lateral and channel bars
    c. Vegetated riparian zones that receive periodic inundation
3. Presence of sensitive species that reflect suitable water quality levels
    a. Rare or threatened fish species that depend on appropriate timing of variable flows for feeding and reproduction
    b. Sensitive invertebrate species that indicate subtle fluctuations in water quality and pollution levels
    c. Important riparian plant species that depend on seasonal inundation for germination
4. Adequate provision of human needs by water resources
    a. Year-round accessibility of water for domestic purposes
    b. High water quality to reduce the occurrence of disease
    c. Maintenance of tourism-dependent processes, such as water for wildlife habitats

Reserve flows are not for the purpose of protecting the fish and insects chosen as indicators. Rather, the reserve is intended to protect the ecological processes and services indicated by the presence of these species, such as degradation of contaminants, breakdown of organic matter and erosion control. These processes are critical not only to the health of the river, but primarily to the health of the human communities that depend on it, many of whom rely on it as their primary source for drinking water.

Study Sites

Site selection began with geomorphological surveys that classified the river into uniform regions based on gradient, channel pattern and bed structure. During initial field visits, the multidisciplinary group of specialists chose a representative site for each region (Figure 4, Appendix 3). The selected sites exhibit fluvial processes characteristic of the macro-reach, as well as represent the interests of multiple stakeholders in the basin. Additionally, these sites incorporate small-scale habitat diversity; as such, all sites were placed on 100 meter-long, straight stretches of the river that included runs, pools and riffles.

Figure 4: EFA sites located in the Mara River Basin, Kenya and Tanzania



Site 1 – Amala River near Kapkimolwa

- **Location:** Amala River, a main tributary to the Mara, at the bridge near Kapkimolwa village, on the border between Bomet and Narok Districts, near gauging station 1LB02
- **Altitude:** 1860 masl
- **Surrounding Land Use:** Small-scale settlement, subsistence farming and cattle rearing

Figure 4: EFA sites located in the Mara River Basin, Kenya and Tanzania (continued)

Site 2 – Mara River near Mara Safari Club

- **Location:** Downstream of the confluence of the Amala and Nyangores Rivers, in the region called Ngerende, north of the boundary of the Maasai Mara National Reserve
- **Elevation:** 1687 masl
- **Land Use:** Wildlife conservation areas, livestock grazing and some large-scale irrigation farming

---

Site 3 – Mara River at Kenya-Tanzania Border

- **Location:** Border between Kenya and Tanzania, and the Maasai Mara National Reserve and Serengeti National Park, just downstream of the Purungat Bridge
- **Elevation:** 1470 masl
- **Land Use:** Wildlife grazing and tourism

Figure 4: EFA sites located in the Mara River Basin, Kenya and Tanzania (continued)

Site 4 – Mara River at Kogatende

- **Location:** Inside the Serengeti National Park 2 km downstream from the Kogatende Rangers' Station
- **Elevation:** 1403 masl
- **Land Use:** Wildlife grazing and tourism

Site 5 – Mara River at Mara Mine

- **Location:** In Tanzania at the gauging station 5H2, Mara Mines, south of Murito Village and north of the Mara Wetland
- **Elevation:** 1183 masl
- **Land Use:** Moderate levels of farming and livestock grazing with large-scale and artisanal gold mining nearby

Site assessments were conducted at Sites 1-3 during March 26-31, 2007, to capture low flows, and during July 16-21, 2007, to capture high flows. Due to unexpected rains, low flows were not captured during these sampling periods, so these sites were re-assessed for low flows from 21-24 February, 2009. During this time, a new site was visited (Site 1.2) on the Nyangores River at Silibwet. Because a full EFA was not conducted at this site, no EFA recommendations were developed for it; however, available data for this site will be included in the sections below. At Sites 4 and 5, field visits were conducted during 7-10 February, 2012, to capture low flows, and during 8-12 May, 2012, to capture high flows.

Field Assessments

Social Indicators

Image 1: Masai dancers from the Mara watershed

Objectives

People rely on rivers not only for water, but also for a wide variety of ecosystem services, including food, medicinal herbs, building materials, and religious practices. The capacity of a river to meet these varying demands depends upon having a sufficient amount of clean water within its channel over time at levels that mimic the river's normal ebbs and flows. Thus, both components of the reserve – basic human need and sustainable aquatic ecosystems – benefit people directly. As human populations increase, there is increased demand for riverine resources by sometimes conflicting interests. People must decide which resources are critical enough to their livelihood that they are worth protecting. Working with local communities is the best way to determine what primary ecosystem services a river provides, to what degree those services depend on certain flow levels, and how those services may have changed over time. The primary objectives of the EFA social assessment were to 1) determine basic human water needs for the projected population in the basin, 2) describe the diversity and importance of in-stream and riparian resources being used by rural communities near the study sites, 3) assess the links between availability of resources and flow of the river and 4) identify current anthropogenic threats to the river ecosystem (Onyango 2007, Mwaipopo 2012).

Methods

Participatory surveys were conducted in communities nearby each study site. For sites within the protected areas, the assessment included tourism activities (Site 3 and 4) and communities living nearby (Site 4). The surveys identified available and utilized resources, primary resource users, relative importance of resources to the communities' livelihoods and seasonal availability of resources in relation to river flow. Consensus was sought among each community on their perception of the current and desired condition of the river as well as current threats.

Results

The first component of the reserve protects basic water needs of people in the basin. The Kenya Water Resources Management Rules (GoK, 2007) defines "basic human needs" as the quantity of water required for drinking, food preparation, washing of clothes, bathing and basic sanitation, and assumes it to be equal to 25 litres per person per day. Based on projections of population increases in the Mara Basin (Table 1), meeting the minimum needs of people in both the Kenyan and Tanzanian portions of the basin required an estimated 0.2 m3/s of flow in 2010 and will increase to 0.3 m3/s of flow in 2020. This assumes that all residents in the basin draw their basic water needs directly from the river. These flows represent only a small fraction of river discharge and are accommodated by the larger flows required to protect the second component of the reserve, which is ecosystem health. It should be noted, however, that these minimum requirements will represent a larger proportion of total flow in smaller headwater rivers and in subcatchments with high population densities, such as the upper Amala and Nyangores Rivers. Thus it may not always be possible to assume that basic human needs are accommodated by flows to protect ecosystems.

Table 1: Population and daily water demand projections (assuming 25 liters/person/day) within the Mara River Basin

	2010		2020		2030	
	Population	Daily Water Demand (m_)	Population	Daily Water Demand (m_)	Population	Daily Water Demand (m_)
KE	556,497	13,912	705,448	17,636	894,268	22,357
TZ	282,204	7,055	361,251	9,031	462,437	11,561
Total	838,701	20,967	1,066,699	26,667	1,356,705	33,918

(Adapted from Hoffman 2007)

The upper reaches of the Mara River Basin (Site 1) have the highest population densities and the majority of people living there depend on small-scale agriculture and livestock keeping. In the middle reaches of the Mara (Site 2), the main livelihoods are nomadic pastoralism or participation to some degree in the tourism industry, although there is also commercial agriculture in this region. The lower reaches of the Mara River in Kenya pass through the Maasai Mara National Reserve (Site 3), and Serengeti National Park (Site 4), in which human population is limited and clustered around hotels and lodges. Communities nearby and downstream of the protected areas (Sites 4 and 5) rely on the river for small-scale agriculture and livestock keeping, and to a lesser degree fishing, artisanal mining and small business.

A large proportion of people in the Mara River Basin live below the poverty level, making them directly dependent on the river ecosystem for a wide variety of goods and services. Surface flows are the major sources of water for people living throughout the river basin, particularly in the more arid middle and lower reaches of the basin. The primary use of the river is for domestic water, although livestock and agricultural irrigation at Sites 1, 2 and 5 also rely on the river. In addition to water, the river ecosystem provides other resources relied upon by local communities, including fish, wildlife, soil and vegetation (Table 2). A resource prioritization chart indicated the most important resource provided by the river at all 5 sites was water, followed by riparian vegetation and the river ecosystem at Sites 1-3, and riparian land at Sites 4-5.

Table 2: Summary of resources utilized by communities in the Mara River Basin and their desired state of the river

River resources	Resource use	EFA Sites	Desired state of the river
Water	Water for livestock	1,2,4,5	Sufficient water to provide for livestock, even during droughts, while maintaining acceptable quality for human consumption
	Domestic use	1,2,3,4,5	High enough water quality for human consumption at all times, including low sediment and impurity loads. The need for point of use disinfection is recognized as well.
	Irrigation for household vegetable gardens and larger-scale cultivation	1,2,4	Sufficient water to sustain crops during the dry season when precipitation is low*

Table 2: Summary of resources utilized by communities in the Mara River Basin and their desired state of the river (continued)

River resources	Resource use	EFA Sites	Desired state of the river
Water	Recreation, e.g. swimming	1,2	Sufficient water to allow swimming
	Industrial use, e.g. water mills, large and small-scale mines	1,2,5	Sufficient water to maintain industry practices*
	Generation of hydroelectric power.	1,2	Sufficient water levels for hydroelectric power generation*
	Cultural /religious practices, e.g. baptism	1,2	Presence of deep pools where people can carry out cultural practices
	Transportation	4	Sufficiently high flows to allow travel by boat
Fish	Home consumption	1,2,4,5	Healthy fish populations
	Sale	4	Healthy fish populations
	Habitats for wildlife	1,2,3	Intact riparian zone that provides habitat and camouflage for wildlife
	Food	1,2,5	Healthy populations of important food plants
	Medicine	1,2,4,5	Flow regimes that foster growth of medicinal herbs that are only found in the riparian zone
	Construction material	1,2,4,5	Intact riparian zones that provide habitat for vines and timber used in construction of local houses, furniture and boats
	Cultural/traditional artifacts e.g. rungus, arrow holders	1,2,4	Intact riparian zones that provide habitat for culturally important tree species
	Reeds for making mats and baskets	4,5	Intact riparian zones and flows that sustain important riparian species
	Charcoal	1,2,4	Presence of large tree species that may be used in charcoal production
	Fuel wood	4,5	Presence of shrubs and trees that can be used for fuel wood
Soil sediments	Soil sediments for art works on houses	1,2	Functioning sediment generation process to provide sediments
	Sand harvesting for construction and sale	1,2,5	Functioning sediment generation process to provide sands
Wildlife	Tourist attraction e.g. crocodile and hippopotamus	2,3,4	Intact habitat to foster thriving wildlife populations
River ecosystem	Cultural practices (e.g. baptism, circumcision, naming ceremonies)	1,2	Sufficient vegetation and deep pools of water to meet cultural needs of the community
	Hotel sites	2,3,4	Adequate water supply and stable river banks to allow construction of hotels and restaurants

*Some of these uses reflect people's desire for flows beyond the reserve to meet extractive water needs as well. These additional needs were acknowledged but not included in final recommended reserve flows. These needs are to be met by flows exceeding the reserve.

Intensity of resource use is dependent on seasons, which influence availability of the resources in a particular area. During the dry season, crossing the river to collect resources and fishing become easier. However, the dry season also intensifies collection of water directly from the river, for domestic purposes, livestock, agriculture and artisanal mining, thus increasing bank degradation due to heavy use. At Sites 4 and 5, fishing with the use of poisonous plants is also more common in the dry season, which can lead to large fish kills. During the rainy season, it is more difficult for people to cross the river to collect resources and travel between communities. However, pressure on the river is reduced due to abundance of streams and temporary dams outside the main river course that allow for water collection and livestock watering near homes and fields.

Local communities were also asked to identify current anthropogenic threats to the river ecosystem. At Sites 1-3, threats included river bank erosion by livestock, high concentrations of pollutants due to human use and destruction of riparian vegetation by cultivation. At Sites 4-5, threats were similar, but included lack of adequate land for cultivation and livestock, due in part to the expanse of the Mara Wetland that led to increased encroachment in the riparian zone, degradation in the Mau Forest and local deforestation. All of these threats were exacerbated in the dry season, when other water sources ran dry and usage was concentrated in the Mara. Overall, people agreed they had seen a decline in resource abundance in the last several decades, including reductions in riparian vegetation and water quality and increases in river bank erosion.

Physical Indicators

Hydrology

Image 2: River gauging station

Objectives

Hydrological analysis of the study sites provides information on the past and present flow regime of the river. A river's flow regime includes not only the quantity of water that flows in its channels during different months of the year, but also the timing of small, annual floods and larger channel-shaping floods. The hydrological analysis is an important input to the overall EFA process because it determines the natural range of flow conditions under which the reserve flow recommendations must operate. The primary objectives of the hydrology study were 1) use historical gauging station and rainfall records to determine periods of low and high flows, 2) document discharge levels during field assessments, 3) guide the specialists in prescribing reserve flow recommendations within the natural range of the river's hydrological regime and 4) extrapolate the reserve flow recommendations across the natural shape of the river's hydrograph (Melesse 2007, Valimba 2012).

Methods

In order to determine historic patterns of flow in the Mara and its tributaries, historic rainfall and discharge records were obtained for the basin. There were 16 rainfall stations with sufficiently thorough records for analysis, and three river gauging stations—the Amala River at the town of Kapkimolwa (1955-2010), the Nyangores River at the town of Bomet (1963-2010), and the Mara River at Mara Mines (1970-2012). Hydrologic data from these sites were extrapolated to fit the five chosen study sites, and were used to calculate monthly average flows and flow duration curves for each site.

Rainfall and streamflow records were used to develop indices for hydrometeorological extremes (droughts and floods) across the basin over the period of record. The Standardized Precipitation Index (SPI) and the Effective Drought Index (EDI) were used to determine hydrometeorological extremes, and the Streamflow Drought Index (SDI) and the Normalized Runoff Index (NRI) were used to determine hydrological extremes. Individual months of each year of record were analyzed according to these indices, and the resulting patterns were used to determine average monthly flow during both normal and drought years. The indices were also used to determine frequency of floods and droughts. These calculations helped guide the specialists in prescribing appropriate flow recommendations, and they assisted the hydrologist in extrapolating flow recommendations over the entire hydrograph. This methodology used in determining average monthly flows for drought versus normal years is more robust than that used in the first EFA report, and it has been applied to hydrological analysis of all five EFA sites.

During EFA sampling, discharge was measured using the velocity-area method. Resulting discharge measurements were compared to those from nearby gauging stations when possible.

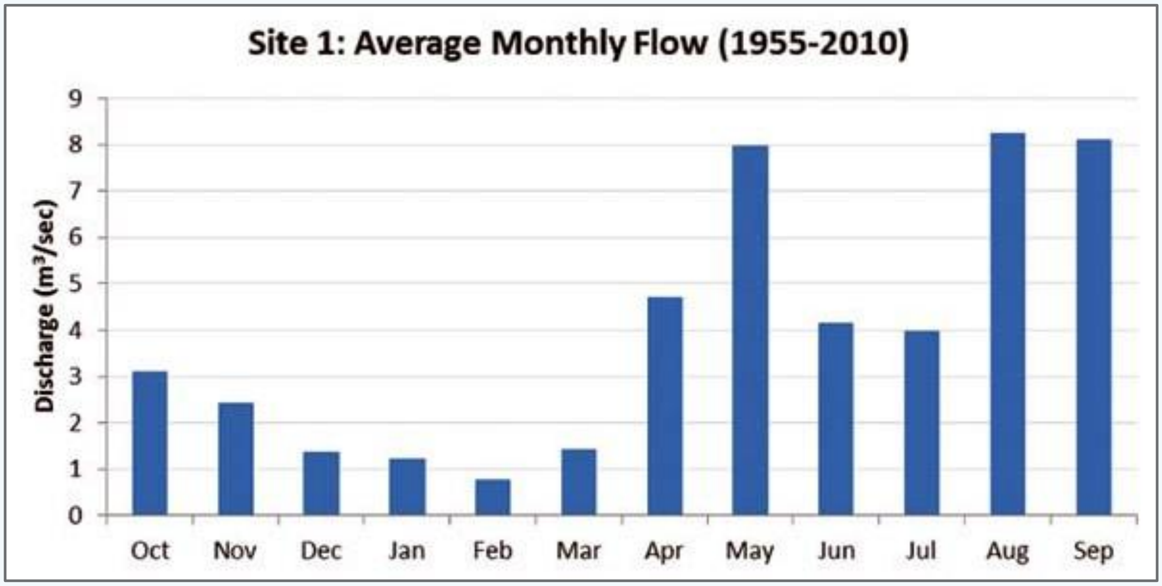
Results

There is a high degree of spatial and temporal variability in rainfall across the basin. Some portions of the basin can experience higher than average rainfall, while others are experiencing lower than average levels. In addition, there is high occurrence of hyrometeorological extremes in the basin—over 58 years of record, 34% of the years were classified as moderate extremes, with 11 being drought and 9 being wet years. In general, the 1970's and 80's were drier years, while the 1980's to present have been wetter.

There are generally two annual peaks in flow levels in the Mara River. One occurs during the long rains from March to June, and the second occurs during the short rains from September to December. Both peak and low flow levels increase from upstream to downstream in the basin. The river has not dried up completely at the study sites in the past fifty years of monitoring, although many of its other tributaries do stop flowing during the dry season. Historical flow data is presented below for Sites 1, 3 and 5; similar data for Sites 2 and 4 can be found in Appendix 4 and 5.

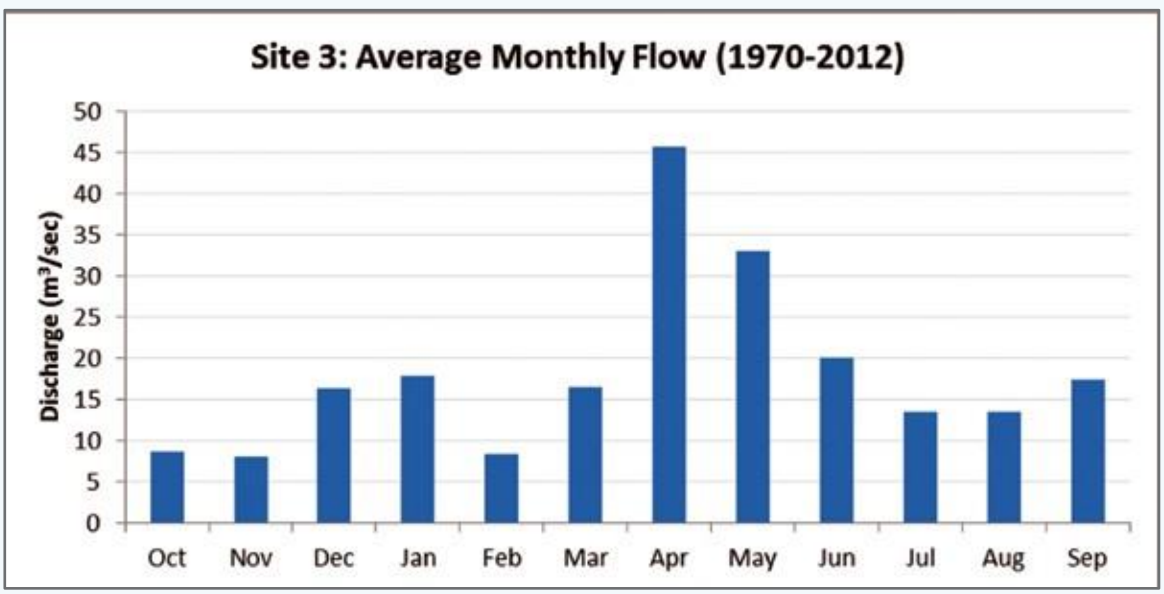
At Site 1, in the upper reaches of the basin on the Amala River, average monthly flows during years with normal rainfall range from 0.7 – 24.5 m3/sec, with an average of 4.0 m3/sec (Figure 5). However, during drought years they can be as low as 0.01, and during wet years, they can be as high as 74.6 m3/sec. Monthly averages are different from daily peak flows, which may extend over 150 m3/sec in a wet year. We present monthly averages here, as they provide a more time-integrated view of the river's hydrology.

Figure 5: Monthly flow at EFA Site 1, averaged over all the years of record (1955-2010)



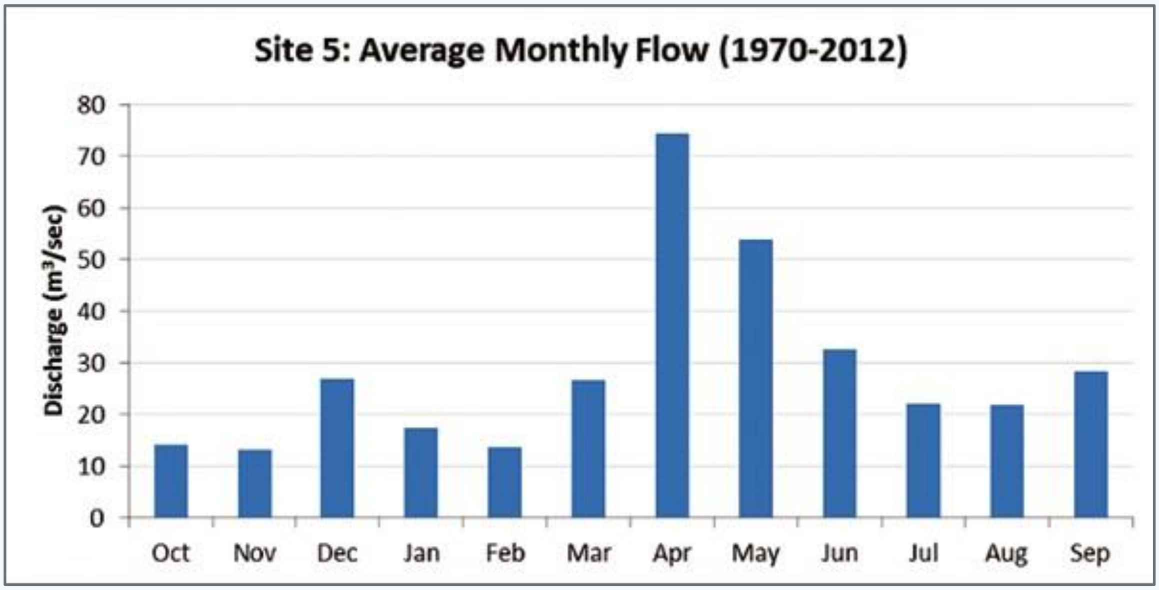
At Site 3, in the middle Mara straddling the Kenya-Tanzania border, average monthly flows during normal years can range from 2.7 to 77.7 m3/sec, with an average of 18.3 m3/sec (Figure 6). However, during drought years they can be as low as 1.1, and during wet years, they can be as high as 296.7 m3/sec.

Figure 6: Monthly flow at EFA Site 3, averaged over all the years of record (1970-2012)



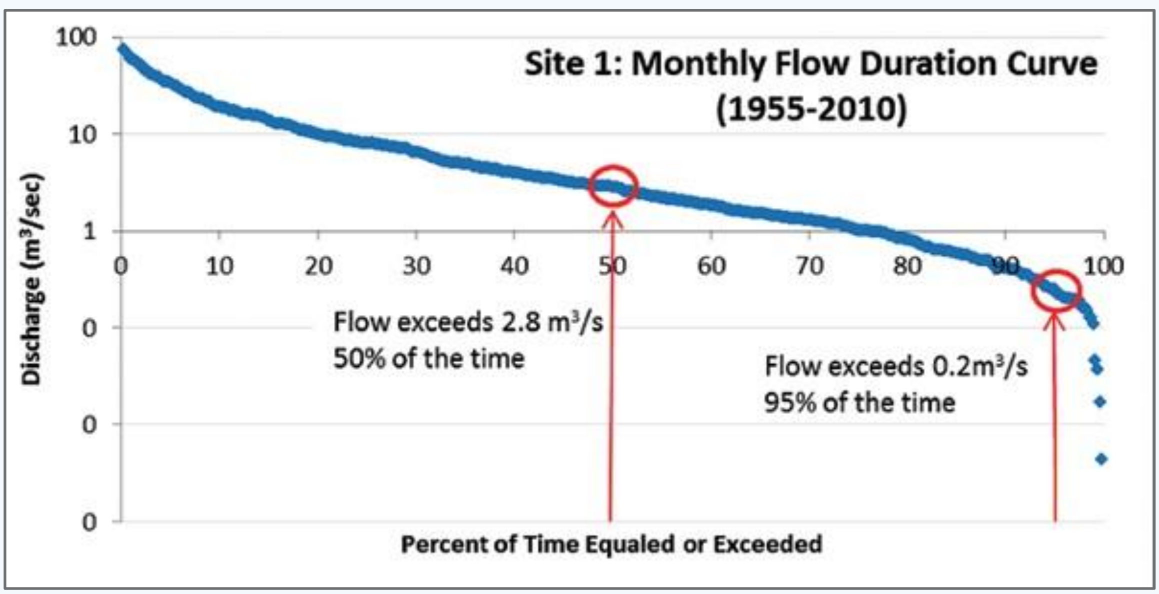
At Site 5, just upstream of the Mara Wetland, average monthly flows during normal years can range from 4.3 to 126.5 m3/sec, with an average of 28.8 m3/sec (Figure 7). However, during drought years they can be as low as 1.7, and during wet years, they can be as high as 483.1 m3/sec.

Figure 7: Monthly flow at EFA Site 5, averaged over all the years of record (1970-2012)



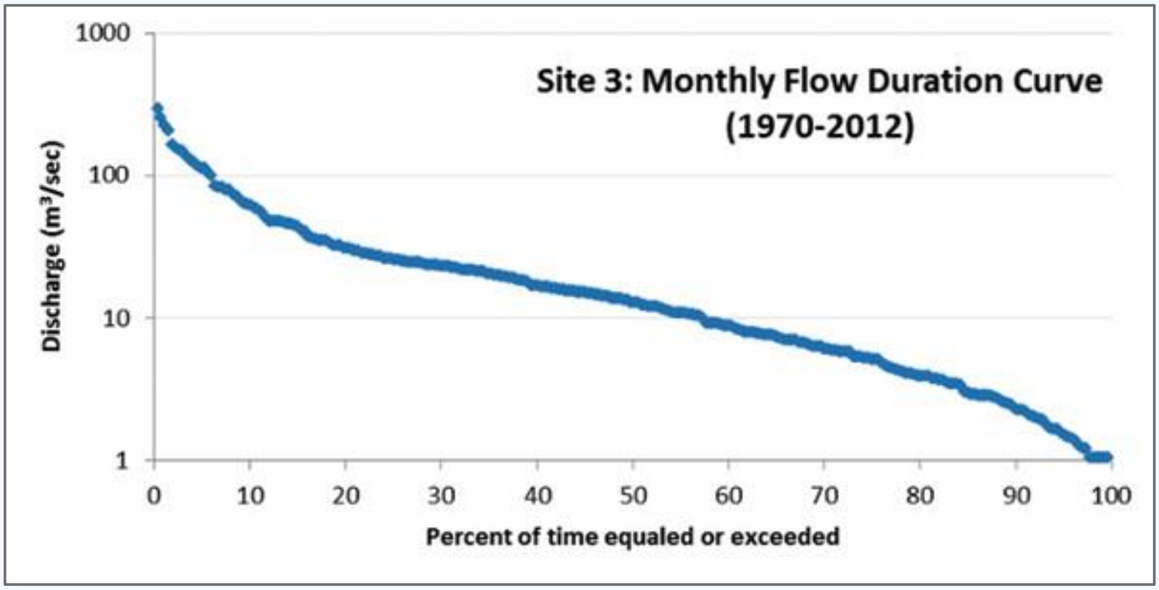
Monthly mean flows at each site were averaged over the period of record to estimate the percent of time the river is likely to exhibit different flow levels. The resulting flow duration curves (FDC) are shown below and indicate, for example, that flow at Site 1 exceeds 2.8 m3/sec 50% of the time and exceeds 0.2 m3/sec 95% of the time (Figure 8). The percent of time that any flow is exceeded can be determined from the curve in a similar manner. The default standard for determining reserve flows in many countries, including Kenya, is the flow level that is exceeded 95% of the time, or Q95. As can be seen on the flow duration curve below, Q95 levels are often very low flows that may be unable to sustain many components of a healthy ecosystem.

Figure 8: Monthly flow duration curve calculated for mean flow levels over the period of record at EFA Site 1



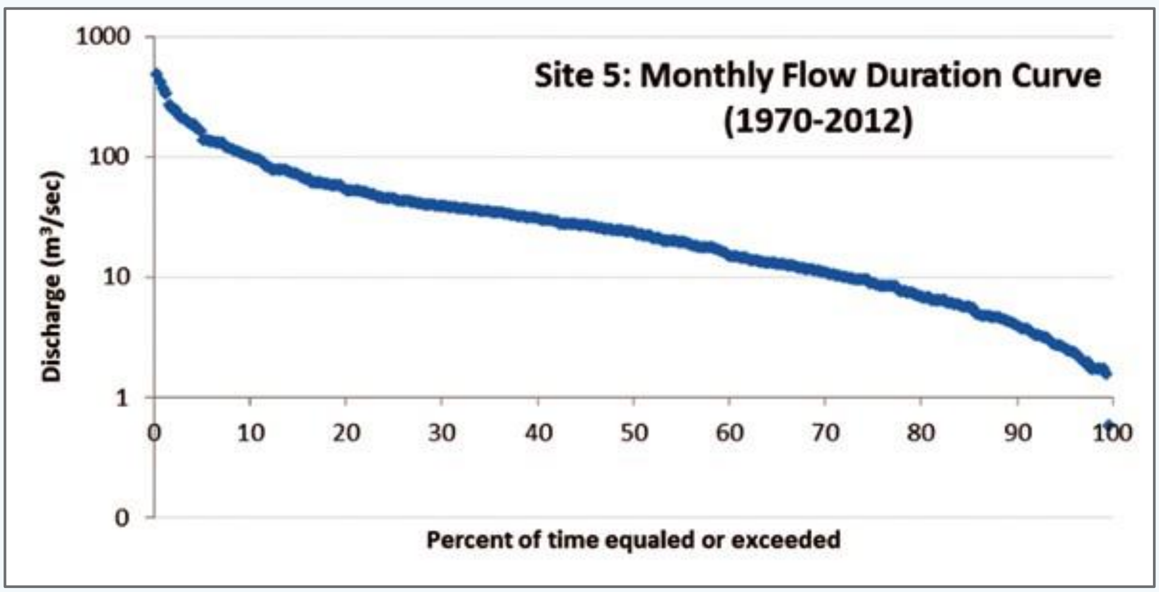
At Site 3, the monthly FDC indicates flows of 1.5 m3/sec are exceeded 95% of the time (Figure 9).

Figure 9: Monthly flow duration curve calculated for mean flow levels over the period of record at EFA Site 3



At Site 5, the monthly FDC indicates flows of 2.5 m3/sec are exceeded 95% of the time (Figure 10).

Figure 10: Monthly flow duration curve calculated for mean flow levels over the period of record at EFA Site 5



Analysis of historic occurrences of wet and dry months were made for each of the three study sites. Once the environmental flow recommendations had been made by the other specialists, the lowest and highest requirements were placed in the driest and wettest months, respectively, and flows were extrapolated for the remaining months in a manner that mimicked the natural flow regime. This was done both for average monthly flows in normal years and in drought years.

Field assessments were targeted to capture periods of low and high flows. Based on the flow duration curves for each site, field assessments succeeded in capturing a wide range of flows at all 5 EFA sites (Table 3).

Table 3: Discharge measurements taken during field assessments and % of time those flows are exceeded according to the flow duration curve for each EFA site

Site	Sampling Date	Total discharge, Q (m3/s)	% Flow Duration Curve
EFA 1	March 2007	1.2	72%
	July 2007	7.9	26%
	February 2009	0.2	97%
EFA 1.2	February 2009	0.6	-
EFA 2	March 2007	6.8	68%
	July 2007	16.9	36%
	February 2009	1.0	98%
EFA 3	March 2007	7.5	65%
	July 2007	15.9	42%
	February 2009	1.1	97%
EFA 4	February 2012	2.6	93%
	May 2012	118	6%
EFA 5	February 2012	2.5	95%
	May 8, 2012*	529.3	0%
	May 9, 2012*	254.9	2%

*Discharge was measured on 8-9 May, 2012 during the falling limb of a flood, so both measurements are presented. The measurement on 8 May exceeded any previous measurement for that site.

Hydraulics

Image 3: Project technical staff surveying river cross sections

Objectives

Local hydraulics and channel morphology are the primary determinants of availability of physical habitat which, in turn is a major determinant of ecosystem function (King et al. 2000). The study of hydraulic effects of a changing flow regime yields a series of relationships between discharge and other flow parameters, including wetted perimeter, water surface width, water depth and flow velocity, that can then be used by the other specialists to translate critical flow parameters into discharge recommendations. The hydraulic conditions are therefore the main link between the ecological requirements for habitat conditions (in terms of flow depth, velocity, wetted perimeter, etc.) and the hydrology (in cubic meters per second). The hydraulic analysis differs from the hydrologic analysis in that it focuses on instantaneous fine-scale relationships between discharge, depth, and velocity rather than longer term flow patterns. The primary objectives of the hydraulic survey were 1) establish transects at each site, 2) survey river cross section topography and water surface elevation, 3) establish river morphology structure, and 4) use hydraulic modelling to project critical variables over a range of discharge levels (Ndomba 2007, 2012).

Methods

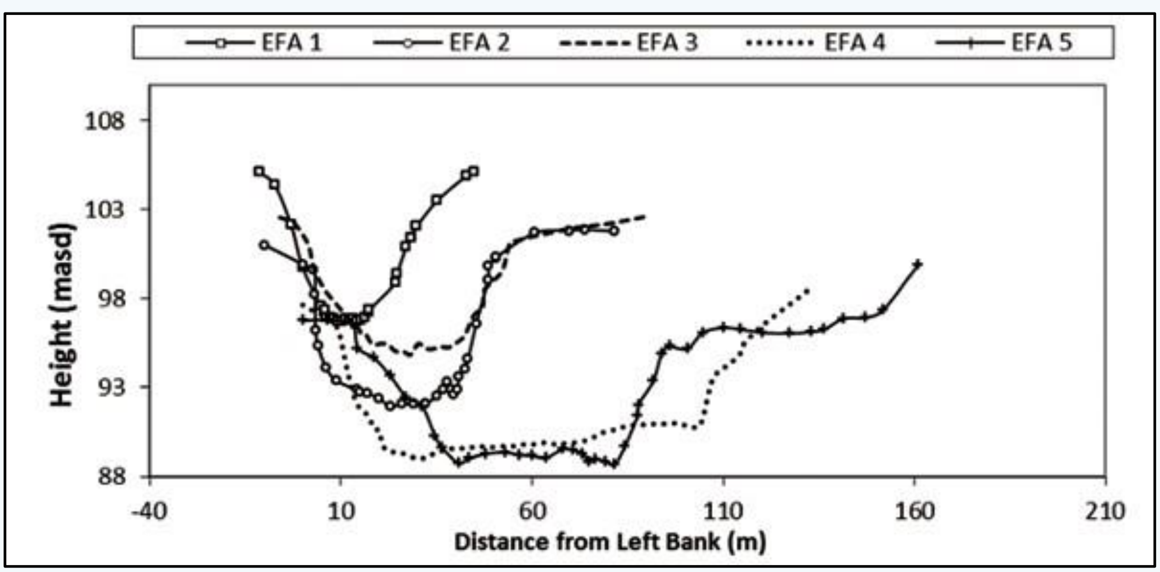
Hydraulic cross-sections were established along 65-200 meter reaches at each site in order to capture variability in habitat types and hydraulic regimes. Each site included 4-6 transects through sections of riffles, pools and runs. A geometric survey was undertaken at each transect using a Theodolite, dumpy level, staff, tape measure and motorized boat to determine distance between transects, water surface elevation (relative to a fixed benchmark), water surface slope (based on the thalweg, or deepest point in the channel), bed elevation profiles, stage of zero flow elevation and water depth. Velocity and discharge measurements were obtained by the hydrologist.

Hydraulic models were developed to relate discharge to the other measured flow parameters, for the purpose of extrapolating hydraulic parameters to discharge levels other than those measured. A Physical Habitat Simulation Model (PHABSIM) was used for Sites 1-3; for Sites 4-5, a HEC-RAS model was used on the basis of issues of data availability. The hydraulic model was calibrated using data collected during low flow sampling and model performance was tested with data collected during high flow sampling. Once calibration was satisfactory, simulated parameters were used to produce rating relationships between stream flow and wetted perimeter, depth, width, velocity, and cross sectional area. These relationships were used by the other specialists in the final workshop to arrive at Environmental Flow Recommendations (EFR) for the Mara River.

Results

There was a surprising level of consistency in macro-channel geometry between Sites 1-3. At each site the river had cut approximately 8 meters below the surrounding land levels, and the width of the macro channel ranged from 45 m at Site 1 to 55 m at Sites 2 and 3. At Sites 4 and 5, the channel was still incised by approximately 8 m, but channel width was much greater than upstream sites, ranging from 110 m at Site 4 to 90 at Site 5 (Figure 11).

Figure 11: Cross-sectional plots of transects at EFA Sites 1-5



A number of hydraulic parameters were measured at each study site in order to develop the models (Table 4).

Table 4: Summary of hydraulic characteristics measured at the EFA sites

Site	Statistic	Measured hydraulic flow parameters				
		Total width of water surface (m)	Total area (m2)	Total discharge (m3/s)	Cross section mean velocity (m/s)	Water surface level (masd)
Site 1	March 2007	10.1	4.7	1.2	0.30	97.4
	July 2007	12.0	10.5	7.9	0.77	98.0
	February 2009	8.8	2.7	0.2	0.11	97.1
Site 2	March 2007	27.7	10.9	6.8	0.63	92.9
	July 2007	27.1	17.8	16.9	0.96	93.1
	February 2009	20.5	5.2	1.0	0.21	92.5
Site 3	March 2007	27.2	20.5	7.5	0.38	96.2
	July 2007	30.2	28.6	15.9	0.57	96.6
	February 2009	19.0	8.2	1.1	0.11	95.8
Site 4	February 2012	19.2	6.5	2.6	0.38	89.34
	May 2012	-	115.1	118.0	1.0	91.38
Site 5	February 2012	20.1	11.7	2.5	0.19	89.41
	May 2012	-	248.5	529.3	2.13	92.78

Model results based on the shape of the river channel and the hydraulic parameters listed above allowed the hydraulics engineer to determine water surface levels (WSL) across different discharge levels (Figure 12).

Figure 12: Model projections for water surface levels (WSL) across a range of discharges (Q) at a) Site 1, b) Site 3 and c) Site 5

a.

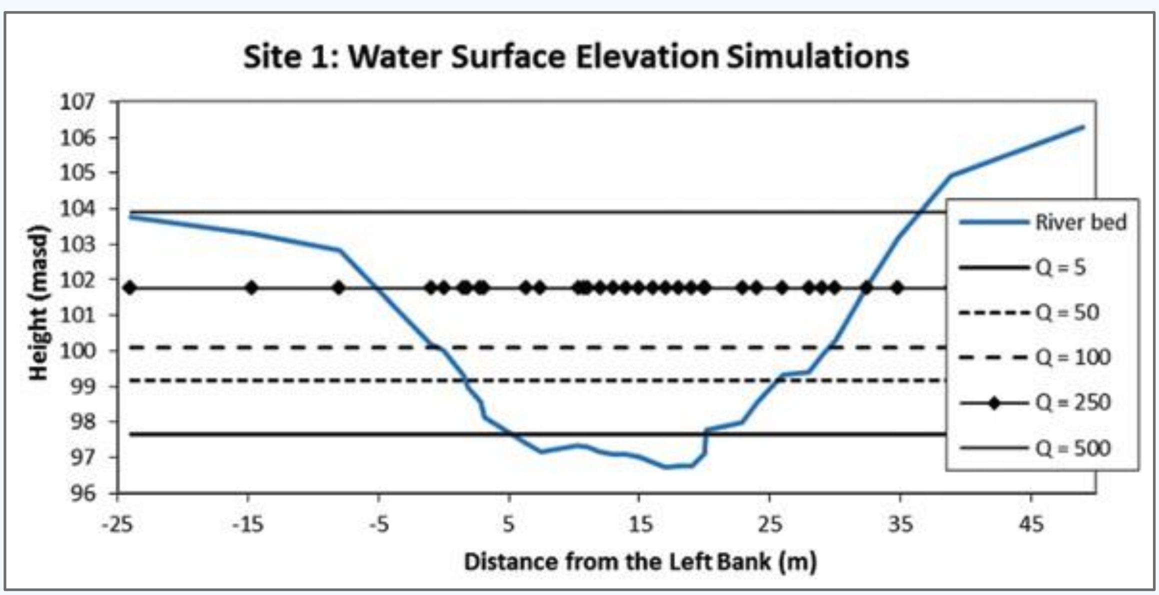
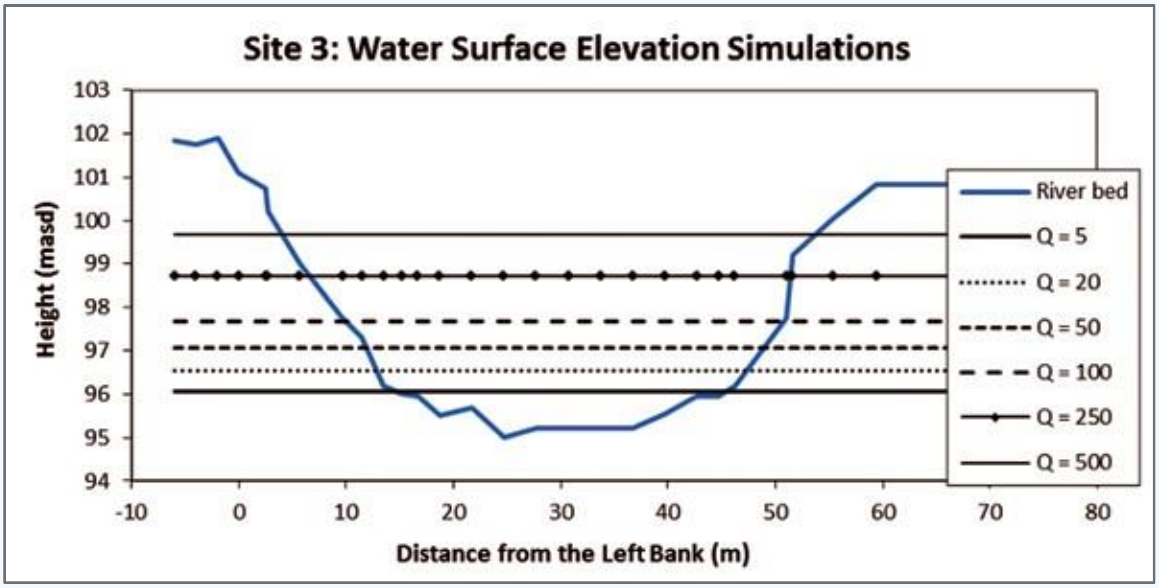
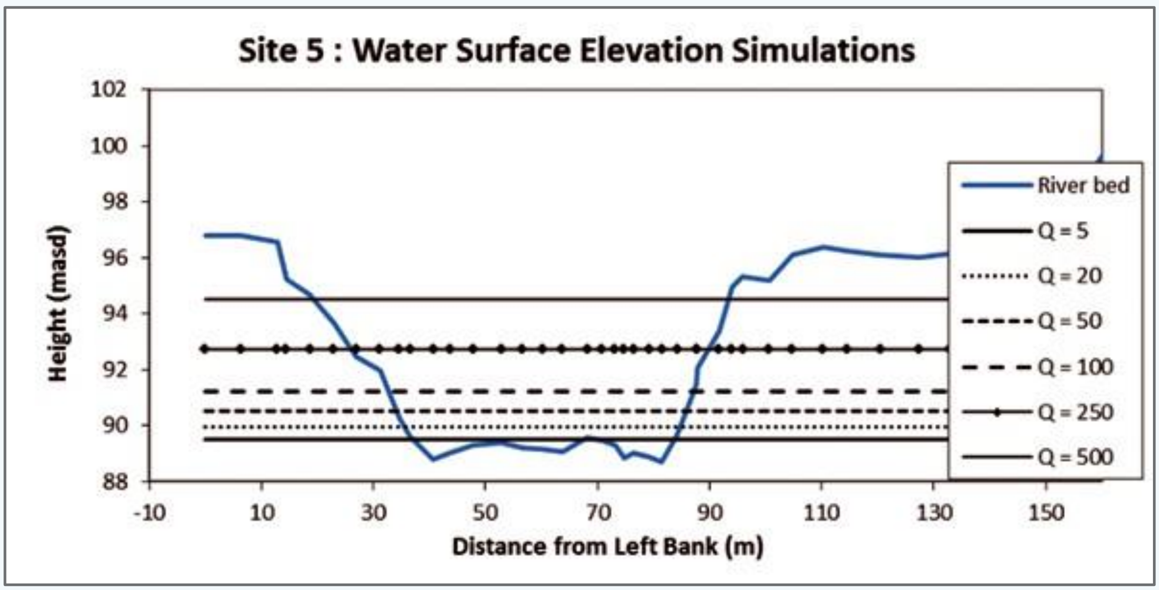


Figure 12: Model projections for water surface levels (WSL) across a range of discharges (Q) at a) Site 1, b) Site 3 and c) Site 5 (continued)

b.

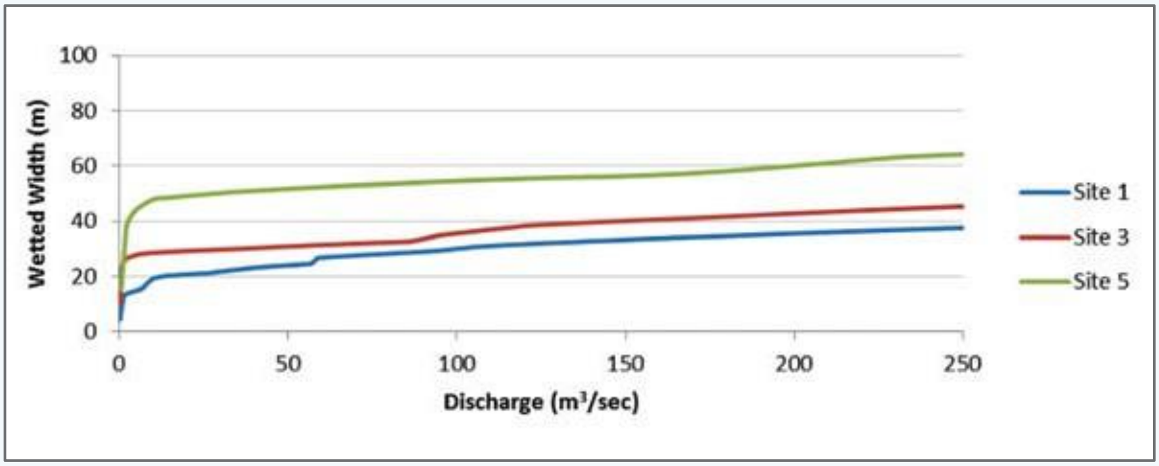


c.



From these model projections, various flow parameters can be graphed as a function of discharge in order to determine critical flow levels (Figure 13). For example, the wetted width of a river is a baseline indicator of how much aquatic habitat is available at any particular discharge. Relationships between wetted width and discharge at all five sites generally had a characteristic shape: steeper at low discharges with one or multiple break points. These break points may correspond to water rising over channel features such as bars and boulders, or an irregular channel bed or banks. Once water fills the channel and begins to rise up the stream banks, the rate of increase of wetted perimeter for each unit increase of discharge decreases. This process creates a break in slope, an inflection point, in the plot of wetted perimeter to discharge. This break point is important in defining minimum streamflow requirements (Gippel and Stewardson, 1998). At Site 1, these break points occurred at 0.5, 8 and 58 m3/sec. At Site 3, they occurred at 0.7 and 90 m3/sec. At Site 5, they occurred at 1.5 and 180 m3/sec.

Figure 13: Simulated relationships between wetted width, a key ecological parameters and discharge at EFA Sites 1, 3 and 5



This and other series of relationships between discharge and flow parameters, including water depth, flow velocity, and wetted perimeter, were used by the EFA team to translate necessary flow parameters for different components of the river ecosystem into minimum required discharge values. For example, the riparian vegetation specialist may recommend a given river width in order to inundate emergent vegetation critical for sustaining in stream habitat. The hydraulic model can then be used to translate this width into a discharge value that can be used by water resource managers.

Geomorphology

Image 4: The Mara river

Objectives

Geomorphologic assessment aids in selection of sampling sites in distinct geomorphological reaches of the basin and analyzes each study site in regards to the shape of the river channel and accumulation of sediments arising from fluvial processes such as erosion, transport and deposition. The low flow assessment describes geomorphologic units that determine critical ecological habitat for river health, and which may be lost during low flows. The high flow assessment determines necessary flows for maintenance of channel form. Understanding how flow level affects the shape of the channel and accumulation of sediment is critical because the resulting physical habitat influences the nature of the entire riverine ecosystem. Primary objectives of the geomorphology report were 1) provide a geomorphologic assessment of the Mara River Basin at a basin, reach and site scale, 2) determine the relationship between diverse channel morphological units and discharge at each site and 3) assess the likely pattern and direction of morphological change for each region of the Mara River (Muthike 2007, Mwanakuzi 2012).

Methods

During the low flow assessment at each site, morphological features along each cross-section were identified and described in terms of substrate material, degree of erosion and deposition and frequency of inundation. Sediments were sampled for particle-size distribution analysis, and median particle size was used to identify the velocity required to mobilize sediments. During the high flow assessment, mobility and transformation of geomorphologic units identified during the low flows was investigated. In addition impact of high flows on the channel plan and cross-section were identified and described.

Results

All five study sites showed some degree of terracing, along with the presence of areas accustomed to intermittent flooding, although no sites had a well-defined floodplain. All sites also had active channel banks and in-stream sandbars, indicating the occurrence of active processes such as erosion and sediment deposition. Site 1 showed fairly low levels of erosion, with less than 10% of the riverbank affected by undercutting, limited rilling on both banks due to human and livestock paths, and low levels of sediment accumulation on the riverbed. There were some small lateral and mid-channel sand gravel bars, but these comprised less than 10% of the river's width and they had patchy grass cover, indicating a degree of stability. The dominant bed material was mixed cobble, gravel and sand. There was limited bed scouring or sediment deposition, but moderate silt deposition occurred over channel margins.

Site 2 had significantly higher levels of erosion, with up to 75% of the riverbank deeply undercut. These areas were accompanied by a lack of vegetation along the riverbanks and deep gullies forming along moderately trampled human and wildlife trails. There were small lateral and mid-channel sand and gravel bars comprising less than 10% of the river's width, with limited vegetation cover. Dominant bed materials were cobbles and boulders, with moderate bedrock pavement, and only localized silt deposits. This was one of the most heavily impacted reaches of river in terms of geomorphology.

At Site 3, there was less erosion than at Site 2, although there was undercutting along 33-75% of the banks and some bank slumping was occurring. Banks were sparsely vegetated, with active gullying along moderately trampling wildlife tracks (Figure 14). There were limited lateral silt and sand bars, comprising only 5% of the river's width and lacking any vegetation. The dominant bed material was bedrock and boulders and extensive bedrock pavement. There was localized silt deposition in pools, and moderate silt deposition along channel margins.

Site 4 was terraced with a deeply incised channel and an upper terrace that did not receive frequent inundation. There was a high degree of bank erosion, with slumping occurring along 33-75% of the banks, resulting in active channel widening. Extensive erosion was occurring along the slumped banks, due to the highly erodible silt/clay soil type, lack of vegetation and heavy use by humans and livestock. There was widespread occurrence of lateral sand bars—at low flows, the largest bar occupied 90% of the channel—however, they were mobile under higher flows. The dominant river bed material was primarily sand, with some gravel and cobble in riffles. There was no indication of erosion on the alluvial channel, but deposition was occurring in shallow pools and riffles during low flows. High flows removed sandy deposits on the bed and bars, but initiated new bank slumping. This site was the other heavily impacted river reach in terms of geomorphology.

Site 5 was also terraced with an incised channel and an upper terrace that appeared to be rarely inundated, although it was less incised than Site 4. Bank erosion was occurring on 33-75% of the banks, with moderate to extensive rilling and gullying due to poor vegetation cover, heavy livestock impact and cultivation occurring close the banks. This erosion led to some bank slumping, although there are no signs of recent channel incision or shifting. A variety of sand bars had formed in the alluvial channel, occupying up to 50% of the channel width, with lateral bars most common, followed by mid-channel bars, and some unstable braided bars. Despite localized areas of boulder and bedrock, the river bed was primarily alluvial and comprised of sands. There is no indication of erosion on the riverbed, but there are common indications of deposition, including sand bars, deposition on banks and pools and overbank deposition. Although high flows removed most of the sandbars and bed deposits, they deposited the sediments on the banks and in channel avulsions, leading to a net stable channel that is neither aggrading nor degrading.

Figure 14: Deep gullies formed along the riparian zone by wildlife trails at Site 3

Flow Recommendations

In assessing required environmental flows for the geomorphology of these reaches, low flows are important for sediment deposition and to maintain biological processes; however, they are least active in channel-forming processes. Primary environmental flow recommendations are made in regards to high flows (small and large floods of varying magnitude, duration and frequency), which may be less likely to occur in heavily utilized river systems. High flows can be either channel maintenance floods, which overflow the benches of the active channel, or channel forming floods, which maintain the geometry of the macrochannel and replenish sediment supply to floodplains. Channel maintenance flows are the most critical driver of fluvial processes within the active channel, and should occur at least once per year to maintain active channel banks, replenish sediment supply to lateral bars and flush out finer sediments. Due to the highly entrenched nature of the channel at all the EFA sites, only very large flood events are likely to reshape the macro channel or replenish sediment deposits on the high terraces, and due to the absence of a well-defined floodplain, these can occur more infrequently.

At Site 1, annual floods during wet years are necessary to maintain firm, well-vegetated mid-channel bars and banks. Infrequent large flood events, approximately every five years, are required to maintain the macro channel features, such as terraces and wider banks. Small floods during dry periods are needed to flush out accumulated silt and sediment deposits from the riverbed. At Site 2, one normal flood event during wet years is necessary to maintain active channel features, such as sandbars, benches and terraces of the main channel. One large flood every five to ten years is needed to maintain the high terraces and floodplain of the macro channel. At Site 3, frequent normal floods are necessary in both wet and dry years to maintain sandbars, benches and terraces of the active channel. Infrequent but extreme flood events are necessary at this site to maintain the high terraces and floodplain of the macro channel, to transport sediment of larger size, and to reconstruct macro channel features that may have been degraded by external disturbances. At Site 4, large and long floods are needed approximately every five years to maintain macro-channel banks and deposit sediment on high terraces. Medium floods recurring every one to two years are required to maintain the channel bed and active banks through remobilization of sandy sediments. At Site 5, large floods are needed approximately every five years to maintain macro-channel banks and high terraces through sediment deposition and to mobilize gravel material on the river bed. Medium floods recurring every one to two years are required to maintain the bed and active channel banks, and to mobilize and transport sand bars and fine sediments.

Image 5: Inhabitants along the Mara river basin in many villages use water of poor quality for domestic consumption

Objectives

Water quality is defined as the physical, chemical, biological and aesthetic qualities of water that determine its fitness for human use as well as for maintenance of a healthy ecosystem (DWAF 1996). The Mara EFA water quality assessment provides information on the present state of the river and considers the influences of altered flow levels on the presence and concentration of compounds that could be harmful to humans and aquatic life. The primary objectives of the water quality survey were 1) conduct in situ and laboratory measurements of water quality parameters at EFA sample sites during low and high flows, 2) determine spatial and temporal variation in water quality throughout the basin, and 3) make recommendations about flow levels necessary to maintain suitable water quality (WQBAR 2007, GLOWS 2011, Athuman 2012).

Methods

In order to evaluate overall water quality in the basin and identify potential threats, a water quality survey was done throughout the length of the Mara River Basin in May-June, 2005 and 2006, and the findings were incorporated into the EFA for Sites 1-3 (WQBAR 2007). Recommendations from the initial EFA report called for more frequent and detailed monitoring to better assess the relationship between water quality and flow level, particularly during low flows (LBVC 2010). In response to this recommendation, twice monthly monitoring was undertaken at eleven sites throughout the upper and middle portions of the basin from 2008-09, and water quality results were compared to discharge levels (GLOWS 2011). During the second phase of the EFA, water quality sampling was conducted at Sites 4 and 5 during field assessments at low and high flow levels (Athuman 2011).

During all water quality sampling, water samples were analyzed for temperature, pH, electrical conductivity, total dissolved solids, salinity, turbidity, total suspended sediments, dissolved oxygen, nutrients and major ions. A subset of samples was further analyzed for the presence of heavy metals and pesticides. The influence of flow level was considered in relation to the mobilization of contaminants during high flows, the formation of isolated pools that may develop dangerous water contamination during low flows, and the general concentration of contaminants in the river during low flows.

Results

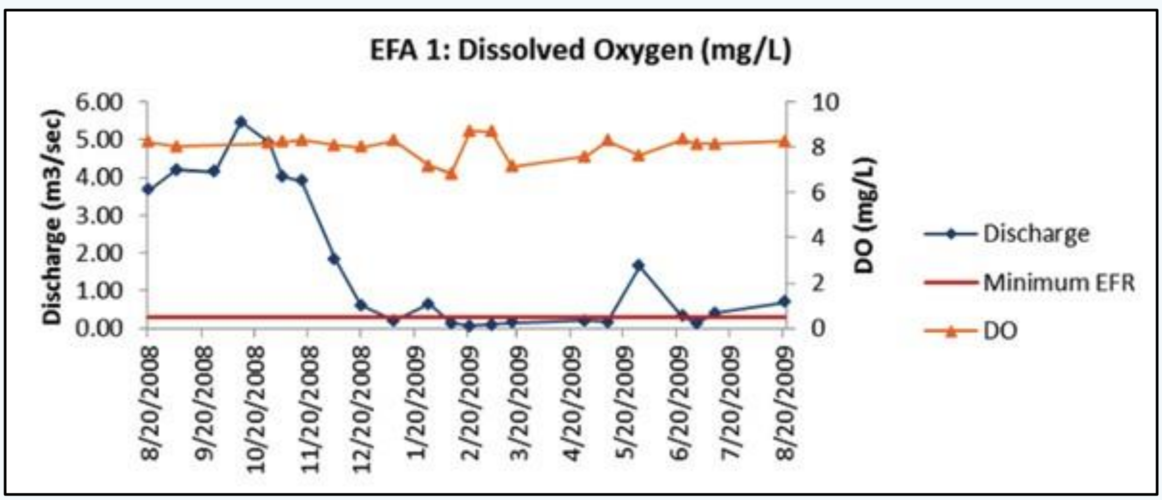
The basin-scale assessment done in 2005-06 found that water quality was generally acceptable, as no parameters were measured at concentrations exceeding national or international water quality standards. Temperature, conductivity, total dissolved solids (TDS) and salinity all increased on the Amala River from the source to the confluence; however, levels on the Nyangores remained consistent. Conductivity, TDS and salinity are measures of the mineral content of natural waters, and low conductivity and TDS are often characteristic of forested rivers; however, it's thus far difficult to tell if differences between these rivers are natural or the result of anthropogenic changes (WQBAR 2007). Total dissolved nitrogen (TDN), dissolved organic nitrogen (DON), ammonium ($NH4+$), total dissolved phosphorus (TDP), and phosphates ($PO43-$) were all much higher at Site 1.2 in 2005 than any other site, but this effect was not as pronounced in 2006. These high levels of nutrients may be due to fertilizer use in this tea-producing region. Levels were below World Health Organization (WHO) maximum contaminant levels for drinking water but may be contributing to eutrophication downstream.

The basin-scale assessment done in 2005-06 also found that total mercury (THg), which ranged from 1.09 – 11.20 parts per trillion (ppt), and aluminum (Al), which ranged from 60.5 – 8194 parts per billion (ppb), were well below WHO standards for drinking water, and Kenyan and Tanzanian effluent standards. The levels were higher inside the protected areas than up- or down-stream; however, given the tendency of these metals to bond to sediments, these elevated levels may be related to the higher levels of total suspended solids found within the reserves, as those samples were taken after heavy rainfall events (WQBAR 2007). Because these heavy metals bioaccumulate and biomagnify in nature, even low levels may result in harmful accumulation in wildlife and people.

Data collected in the upper and middle portions of the basin from 2008-09 found that water quality was strongly affected by low flow levels, particularly at sites further downstream (EFA Sites 2 and 3). Results are shown below for dissolved oxygen (DO), which tends to decline under poorer water quality (Figure 15). Low DO levels can have direct, negative effects on the biological health of a river. At both Sites 2 and 3, when discharge levels dropped below the drought year, low flow environmental flow recommendation (Minimum EFR), DO levels dropped to below 2 and 3 mg/L, respectively. DO levels below 3 mg/L are generally considered to be harmful to aquatic life and are below Tanzania's standards for the poorest category of receiving waters. These findings lend support to the importance of maintaining discharge above the minimum EFRs.

Figure 15: Dissolved oxygen and discharge measured twice monthly from August 2008- August 2009 at a) EFA 1, b) EFA 2 and c) EFA 3, as compared to the environmental flow recommendations (EFR) for drought year dry season flows at that site

a.



b.

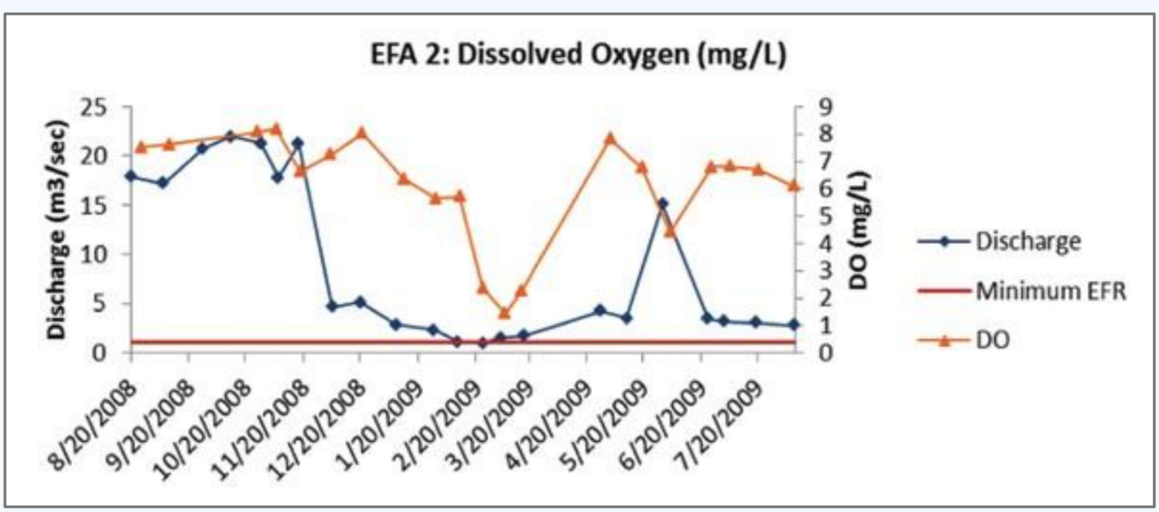
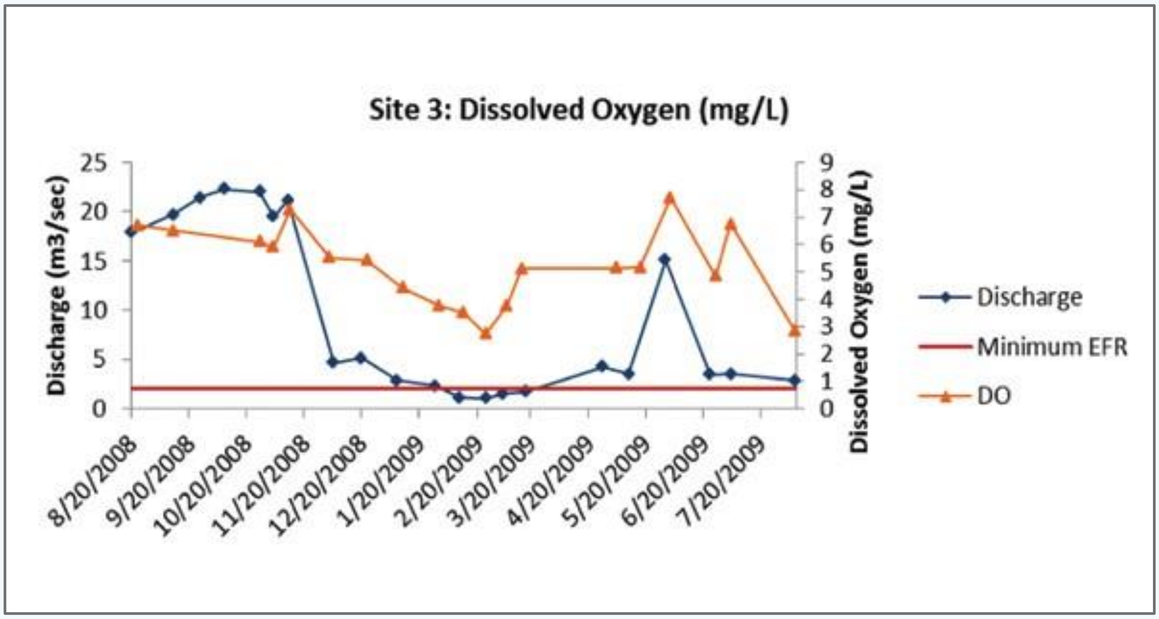


Figure 15: Dissolved oxygen and discharge measured twice monthly from August 2008- August 2009 at a) EFA 1, b) EFA 2 and c) EFA 3, as compared to the environmental flow recommendations (EFR) for drought year dry season flows at that site (continued)

c.



The Amala sub-catchment (Site 1) had overall poorer water quality that the Nyangores sub-catchment (Site 1.2), suggesting land use change in this area may be causing problems to water quality in the basin. Water quality indicators suggested Site 2 was in the poorest ecological condition of all sites surveyed in the upper and middle basin, particularly under very low flow conditions. However, some water quality parameters improved by Site 3, which may be due to the role of the protected area of the Maasai Mara National Reserve in allowing the river to recover. Substantial declines in water quality were also noted along the Talek River from the upstream to downstream site. In fact, the downstream site on the Talek had the poorest water quality of all surveyed sites. More focused monitoring will be needed to determine the role of urban and tourism developments in causing these changes. Because this tributary enters the Mara inside the National Reserve between Sites 2 and 3, it could impede the ability of the river to recover in this region. A summary of water quality parameters at Sites 1, 1.2, 2 and 3 collected during high flows (October 2008) and low flows (February 2009) are in Table 5.

Water quality parameters at Sites 4 and 5 during low and high flows were found to be satisfactory compared to Tanzanian water quality standards for natural rivers, with the exception of turbidity and biological oxygen demand (BOD). Turbidity is a measure of the amount of suspended sediments in the water, and Tanzanian standards call for maximum turbidity levels of 30 NTU in domestic water sources. Low and high flow turbidity measurements at the EFA sites ranged from 27.6 to 686.0 NTU, respectively, indicating high loads of erosion and sediment runoff in the basin. BOD is a measure of the amount of oxygen in the water utilized by aerobic organisms in decomposing organic substances. Tanzanian standards call for BOD levels in natural waters to be between 5-30 mg/L; however, levels at EFA sites ranged from 65.5 to 89.1 mg/L under low flows. These levels could be due to high loading of organic matter or nutrients into the river from either natural or anthropogenic sources, although nutrient levels were within allowable levels for natural, unpolluted waters. In regard to toxic contaminants, water samples had no detectable levels of mercury, pesticides and phenols. Trace levels of blue copper were found, ranging from 0.12 to 0.19 mg/L at Mara Mines and Kogatende, respectively.

Water samples from Kogatende had higher levels of turbidity, nutrients and BOD than those at Mara Mines, although DO levels were slightly higher as well. These data suggest the upstream site has higher loading of nutrients and organic matter than the downstream site, possibly due to effects from the upper catchment or from wildlife activities in the protected areas; however, the system is not yet eutrophic. A summary of *in situ* water quality parameters is in Table 5.

Table 5: Water quality parameters measured at EFA sites during low and high flows*

Site	Flow Conditions	pH	DO (mg/L)	EC (µs/cm)	TDS (µg/L)	Turbidity (NTU)	Temp (°C)	TN (mg/L)	NH_4 (µg/L)	TP (µg/L)	SRP (µg/L)
Site 1	Low	8.6	8.7	239	155	45.9	21.4		103	20	<100
	High	7.1	8.2	53	34	67.2	17.8		145	<20	<100
Site 1.2	Low	9.0	7.3	81	53	17.5	17.8		51	30	<100
	High	7.0	7.8	42	27	51.7	18.5		203	<20	<100
Site 2	Low	7.8	2.4	431	280	72.1	24.5		76	<20	<100
	High	7.3	8.1	82	54	91.9	20.5		152	50	<100
Site 3	Low	8.0	2.8	567	368	74.5	25.4		135	100	<100
	High	7.1	6.1	122	79	330	24.2		291	<20	<100
Site 4	Low	8.7	8.6	362	234	53.4	26.3	1.03	395	260	64
	High	8.2	8.5	74	48	686.0	20.1	1.25	300	680	150
Site 5	Low	8.9	7.3	368	239	27.6	26.9	0.63	201	160	28
	High	7.9	8.5	121	78	647.5	22.3	2.37	165	560	190

*Analysis instruments and methods varied between Sites 1-3 and Sites 4-5, which may account for some minor differences in parameter measurements across sites

Flow Recommendations

Water quality is strongly influenced by variables other than flow—specifically, natural and anthropogenic inputs of chemical compounds upstream of a given site. However, flow recommendations made by the EFA focused on direct impacts of flow on water quality, assuming proper pollution control measures are instituted at and above the sites. Flow levels should not be prescribed to allow for pollution, but a river with lower flows will be more vulnerable to pollution. The primary objectives for recommended flows at all three sites were to maintain low flows at levels high enough to dilute natural and treated anthropogenic waste products and to maintain levels of turbulence sufficient to promote water aeration. Flow objectives also sought to maintain floods at levels sufficient to flush side channels and isolated pools that might otherwise become stagnant and accumulate waste.

Specifically, flows no less than 0.1 m3/s were recommended for Site 1 in order to maintain dissolved oxygen at a level of 5 mg/L, THg at levels less than 1 µg/L and pesticides less than 1 part per billion (ppb). It was also recommended that turbidity be less than 100 NTU during base flows, although this objective must be reached by controlling upstream erosion rather than controlling in-stream flows. For Sites 2 and 3, flows were recommended to be no less than 1 m3/s in order to maintain high water quality, although acceptable turbidity levels during base flows were increased to 200 NTU. For Site 3, flows were recommended to maintain PCB levels at less than 0.5 ppb. At Site 4, dry season low flows were recommended to be no less than 0.4m3/s, and at Site 5 no less than 0.3m3/s, to accommodate downstream abstraction and maintain DO levels greater than 5mg/L and discourage eutrophication of organic matter. Wet season high flows should not go below 0.5 - 0.75m3/s to maintain aeration of water column. In addition, it was recommended that water quality from smaller tributaries, such as the Tigite River, be monitored, as these will be disproportionately affected by low flows.

Biological Indicators

Biological indicators of a river's intact flow regime include those groups of species most sensitive to short- and long-term changes in the depth, width or velocity of flow level. Biological indicators are typically riparian vegetation, aquatic macroinvertebrates and fish, as these groups are found in all river systems and the occurrence and abundance of certain species in each group can be tightly linked to flow levels. In the Mara River, large wildlife including hippopotamuses and crocodiles are also affected by flow level, and prolonged periods of low flows as well as large floods have been documented to have negative effects on these groups. However, due to the size and mobility of these large wildlife, they are often less highly dependent on short-term changes in a river's flow regime. Thus, flow levels that are adequate for more sensitive indicators, such as riparian plants, aquatic macroinvertebrates and fish, should be sufficient to provide for larger wildlife as well.

Riparian Vegetation

Image 6: Arial view of the Mara river

Objectives

Riparian vegetation is important for maintaining stability of river banks and reducing erosion, retaining and processing overland runoff before it enters the river, sustaining low flow levels through a storage effect, providing resources for instream fauna through input of vegetative detritus, and providing canopy cover that mediates water temperature. It is also used by many communities living on or near the river for food, medicine and building materials. Loss of riparian vegetation can threaten many of the environmental services it provides. Riparian vegetation is a good indicator of both low flow and high flow requirements, because individual species have different and often highly specific inundation and soil moisture requirements for their regeneration. Significant alterations in the natural flow regime of a river may eliminate overbank flooding or affect the floodplain water tables, which could lead to the loss of some species important for human use. The primary objectives of the riparian vegetation assessment were 1) describe important riparian plant communities at each study site, 2) assess the flow dependence of those communities, 3) identify species that may be flow sensitive and can serve as indicators of an appropriate flow regime (Ayieko 2007, Mligo 2012).

Methods

Vegetation surveys were conducted in sample plots placed along transects running perpendicular to the river bed. In each sample plot, information was recorded on species composition and size classes, and vegetation zones were classified according to dominant plant species. The distribution of species was analyzed in relation to channel geomorphology and hydraulic characteristics, yielding information on the natural flow regime of the river.

Results

At Site 1, the surveyed cross-section showed a successive progression from sedge to grasses in the wet areas to herbaceous species and eventually to shrubs and small and large trees on the drier banks. This succession suggests a relationship with soil moisture content; for example, the wetter west bank had dominant perennials while the steep, overhanging east bank was drier and dominated by annual herbs. There were also several areas that had been cleared for cultivation or were already abandoned, as well as evidence of heavy grazing by livestock. At Site 2, large trees such as *Diospyros abyssinica* and *Prunus africana* dominated the banks, declining into isolated thickets of shrubs 30 m away from the channel. This zonal delineation in response to bank terracing suggests the influence of flooding dynamics, linked to magnitude, duration and return period of high and low flows. At Site 3, woody vegetation was dominated by dry-area shrubs. The only large trees present were *Acacia hockii* and one *Ficus sp.,* typical of seasonally drained grasslands. There were also herbaceous species present indicating anthropogenic land disturbance, as well as evidence of heavy grazing by wildlife. At Site 4, the dominant riparian community was composed of shrubs and sedges near the base of the channel and along the banks of seasonal tributaries. There were no riparian tree species documented, and the upper banks transitioned quickly to terrestrial vegetation. This was possibly due to insufficient base flows, a high degree of grazing by wildlife, and eroding and widening channel banks. At Site 5, there was more extensive riparian vegetation both within the river channel and along the banks, including trees, shrubs and sedges, and significantly higher species diversity than at Site 4. However, riparian vegetation was being threatened by heavy grazing and trampling by livestock, tree harvesting for development, and cultivation of agricultural crops close to the bank.

Reductions in riparian species abundance and diversity, particularly at Site 4, could be due to a number of factors that may act in feedback loops with one another. If declining base flows are no longer able to provide sufficient moisture, and rapidly receding high flows don't inundate banks long enough to provide necessary moisture or nutrients, certain flow-dependent species may be lost. Grazing and trampling by wildlife and livestock, which increase during low flows as rangeland forage declines, can lead to increased bank erosion and further declines in vegetation. Reduced vegetation abundance leads to unstable banks and increased rates of erosion, which in turn reduce the ability of new riparian vegetation to take hold. Lack of canopy cover from riparian plants also increases the amount of sunlight reaching the water surface, further increasing temperatures and evaporation rates, and lowering low flows. Continued monitoring of flow-sensitive species, indicated in Table 6, will be important to ensure base flows, maintenance flows and floods are sufficient to sustain healthy riparian vegetation communities.

Table 6: Riparian vegetation at the EFA Sites and their relation to flow levels

EFA Site	Vegetation Zone	Vegetation Type	Dominant Species	Indicator of Flow Level
Site 1	River channel and lower banks	Grasses and sedges	Pennisetum clandestinum, Cyperus macrostachyos	Sensitive to low flows
	Upper banks and terraces	Shrubs and small trees interspersed with herbs	Vangueria madagascariensis, Rhus natalensis, Euclea divinorum, Erlangia cordifolia, Ocimum suave, Ageratum conyzoides	Indicators of high ground water
Site 2	River channel and lower banks	Grasses and sedges	Cyperus macrostachyos Hyperrhenia cyambaria	Sensitive to low flows
	Upper banks and terraces	Large trees and dry area shrubs	Diospyros abyssinica, Prunus africana, Warburgia ugandensis, Lippia javanica, Croton dichogamus	Indicators of moist, riverine forest
Site 3	River channel and lower banks	Grasses	Panicum maximum Cynodon dactylon	Sensitive to base flow levels
	Upper banks and terraces	Few large trees, mostly dry area shrubs	Acacia hockii, Ficus sp., Rhus natalensis, Croton dichogamus, Grewia bicolor, Carissa edulis	Indicators of dry grassland with seasonal patterns of flooding and drainage
Site 4	River channel and lower banks	Grasses and sedges	Pennisetum purpureum, Cyperus articulates, Cyperus denudatus, Leersia hexandra, palm trees	Sensitive to base flow levels and seasonal flows

Table 6: Riparian vegetation at the EFA Sites and their relation to flow levels (continued)

EFA Site	Vegetation Zone	Vegetation Type	Dominant Species	Indicator of Flow Level
Site 4	Upper banks and terraces	No riparian trees present, only terrestrial shrubs	Croton microtachys	Indicator of insufficient base flows
Site 5	River channel and lower banks	Trees, shrubs and sedges	Cyperus articulates, Sesbania greenwayi, Ficus exasperata, Acacia xanthophloea	Sensitive to low flows
	Upper banks and terraces	Large trees	Ficus sur, Ficus lutea, Ficus exasperata, Trichilia emetic, Acacia xanthophloea, Acacia polyacantha, Sesbania greenwayi	Sensitive to base flow levels

Flow Recommendations

Specific flow recommendations for each site were developed in regard to critical indicator species. At Site 1, maintenance flows throughout the year are needed to maintain density and appropriate age structure of *Syzygium cordatum* and *Warbugia ugandensis* and to recharge the groundwater table to sustain woody species. Maintenance year wet season flows are needed at Sites 1 and 2 to maintain sedges and grasses in the channel and to promote seed germination and dispersal. At Site 2, sufficient high flows should also provide sufficient soil moisture to sustain woody vegetation on the upper terraces, including *Diospyros abyssinica* and *Prunus africana*. At Site 3, maintenance flows and flood events are important to foster recruitment and sustain appropriate density and age structure of the few flow-sensitive trees, including *Ficus sp., Rhus natalensis,* and *Carissa edulis*. At Site 4, base flows should maintain survival of in-channel species, particularly *Pennisetum purpureum*, *Cyperus articulatus* and *Leersia hexandra*, and provide sufficient soil moisture to allow growth of riparian trees on upper banks. High flows should raise the water table so it can be accessed by riparian tress and promote germination of seeds. At Site 5, base flows should maintain survival of F*icus sur*, *Ficus exasperata*, *Leersi hexandra*, *Cyperus articulatus*, *Cyperus denudatus*, *Echnocloa scabra*, *Polygonum senegalenses*, *Sesbania kiniensis* and *Pennisetum purpreum*. High flows should provide sufficient moisture for roots of trees and allow seeds of riparian trees to germinate and increase bank stability.

Aquatic macroinvertebrates

Image 7: FIU GLOWS staff digging out a macroinvertebrates survey

Objectives

Aquatic macroinvertebrates are excellent critical indicators of sustainable flow levels because many families react predictably to changes in water quality, and their occurrence and abundance can serve as an integrated measure of the ecological health of the river over the previous weeks or months. Species used in these surveys included insects, worms, mollusks and crustaceans that occur on the riverbed or along the channel margins. The primary objectives of the macroinvertebrate survey were 1) describe and quantify important macroinvertebrate communities at each site during low and high flows, 2) assess the dependence of these communities on flow level, and 3) identify species of conservation significance and invasive or introduced species (Wasonga 2007, GLOWS 2011, Tamatamah 2012).

Methods

In 2007, macroinvertebrates were sampled at EFA Sites 1-3 during low and high flow levels as part of Phase I of the EFA. In response to recommendations made in the EFA report (LVBC 2009), more detailed macroinvertebrate sampling was undertaken at these sites, as well as Site 1.2, from 2008-09 (GLOWS 2011). During this sampling, macroinvertebrates were sampled by kick-netting with a 500 µm kick net in pools, riffled, runs and emergent vegetation, for a total of 16 sub-samples per site. In Phase II of the EFA,from 2011-12, Sites 4 and 5 were surveyed for macroinvertebrates using a Surber sampler (limited to shallow reaches during low flows) and a standard hand net/scoop net. Samples were collected in riffles, pools and marginal vegetation, for 3 sub-samples per site. During all sampling efforts, macroinvertebrates were collected in the field and preserved using 70% ethanol until they could be sorted and identified in the lab to the lowest possible taxonomic level.

For both Phase I and II sampling, macroinvertebrates at each site were analyzed according to number of taxa and number of individuals. Taxa and sites were also characterized using the South African Sensitivity Score (SASS) and Average Score Per Taxon (ASPT), a scale from 1-15, in which a higher value indicates the taxa or community's overall sensitivity to water quality (Dickens and Graham 2002). Each site was also analyzed for macroinvertebrate species diversity using the Shannon-Weiner diversity index (H'), in which a higher value reflects either the addition of new species or an increase in the even distribution of species throughout the sample.

Results

Macroinvertebrate surveys from 2009 yielded much higher levels of diversity than documented in 2007; however, this was likely due to extensive improvements in sampling methodology and increased sampling time. Due to the more comparable methods used during the 2008-09 and the 2011-12 sampling events, only data from these assessments are presented here.

A total of 24,786 macroinvertebrates belonging to 11 orders and 34 families were documented in the samples collected during low and high flows across all sites in the Mara River. Overall, Ephemeroptera (mayflies), Trichoptera (caddisflies) and Diptera (midges and flies) were the most dominant orders of macroinvertebrates collected. Ephemeroptera and Trichoptera are generally considered to be orders sensitive to water quality, so the predominance of these taxa in the Mara suggests the overall river is in fairly good condition.

Site 1 was in fair condition, with relatively high diversity and sensitivity scores. This was the only site at which the number of taxa and SASS 5 score increased during low flows, possibly due to increased ease of sampling, although the ASPT and diversity index both decreased during low flows, similarly to the other sites. The most sensitive taxa documented here were Perlidae (Plecoptera) and Lepidoptera, both with a SASS score of 12, followed by Leptophlebiidae (Ephemeroptera), with a SASS score of 9. Site 1.2 was in good condition, with high SASS 5 and ASPT scores. The most sensitive taxon at this site was Heptageniidae (Ephemeroptera), with a SASS score of 13, followed by Perlidae (Plecoptera) and Lepidoptera, both with a SASS score of 12. In contrast, Site 2 had the lowest taxon richness and sensitivity scores, resulting in a poor SASS 5 score for water quality and habitat diversity. The most sensitive taxa at that site were Corduliidae (Odonata), with a SASS score of 8, followed by Gomphidae (Odonata) and Hydropsychidae (Trichoptera), both with a SASS score of 6. However, Site 3 seemed to have recovered partially, with increased taxa numbers and sensitivity, particularly during high flows. The most sensitive taxa at that site were Lepidoptera, with a SASS score of 12, and Leptophlebiidae (Ephemeroptera), with a SASS score of 9. Site 4 was in fair condition, with a low number of taxa but a higher overall ASPT. The most sensitive species at this site were Teloganodidae (Ephemeroptera), with a SASS score of 12, and Tricorythidae (Ephemeroptera), with a SASS score of 9. Site 5 was in good condition, with high diversity and sensitivity of macorinvertebrates. In addition to the sensitive taxa documented at Site 4, Site 5 also had three additional sensitive families—Heptageniidae (Ephemeroptera) with a SASS score of 13, Oligoneuridae (Ephemeroptera) with a SASS score of 15, and Perlidae (Plecoptera) with a SASS score of 12.

In general, diversity increased from upstream to downstream throughout the basin (Table 7). This finding is unsurprising, as larger river systems provide more varied habitat that can support a wider diversity of species. However, diversity index values for Sites 1-3 are considered low and indicative of disturbed conditions, while values for Sites 4-5 reflect relatively high diversity and are comparable to the numbers obtained from other studies conducted in Tanzanian rivers. There was not a basin-wide pattern in taxa sensitivity scores, which were highest at Sites 1.2, 3 (during high flows) and 5. This finding suggests there is not a consistent upstream-downstream trend in water quality throughout the basin, but that river health is variable by reach. Across all sites, number of taxa, sensitivity and diversity of macroinvertebrates generally increased during high flow as opposed to low flow conditions, likely due to higher water quality during high flows.

Table 7: Results of aquatic macroinvertebrate field assessments at EFA sites during low and high flows

EFA Site	Flow Level*	No. of Taxa	SASS 5 Score	ASPT	Diversity Index	Classification of water quality and habitat diversity∞
Site 1	Low	19	109	5.74	0.80	Fair
	High	15	88	5.87	0.96	Intermediate
Site 1.2	Low	17	106	6.24	0.84	Good
	High	18	110	6.11	0.97	Good
Site 2	Low	13	57	4.38	0.76	Poor
	High	15	81	5.14	0.87	Intermediate
Site 3	Low	14	72	5.14	0.86	Intermediate
	High	20	122	6.1	1.52	Good
Site 4	Low	10	73	7.30	1.63	Fair
	High[t]	-	-	-	-	-
Site 5	Low	14	107	7.64	1.74	Good
	High	19	126	6.63	2.19	Good

*Data for low and high flows for Sites 1-3 are from February 2009 and September 2008, respectively
∞Interpretation of SASS 5 scores from Chutter 1998; interpreted as Good, Fair, Intermediate or Poor
[t]No macroinvertebrate data available for high flows at Site 4 due to an aggressive hippo

Flow Recommendations

General flow recommendations for aquatic macroinvertebrates include sufficient velocities at low flows to maintain adequate dissolved oxygen levels for survival and reproduction. Normal, more frequent floods are necessary to reset species composition by shifting dominance of some species via drift from upstream. Larger floods that occur on a yearly basis are necessary to flush out accumulated organic matter, promote biomass increase and foster recolonization of habitats. Small spates during the dry season are needed to rejuvenate organic matter levels and improve stagnant water quality. Specific flow recommendations were made for each site depending on the presence of critical, flow-sensitive indicator species. For example, the nymphs of stoneflies (Perlidae: Plecoptera) are found under rocks, stones and amongst dead leaves in fast flowing streams (velocities ≥ 0.25 m/s) and have very low resistance to pollution.

At Site 1, adequate flow levels are required to maintain populations of Perlidae and Hydrosychidae, as some species are eliminated when the water becomes stagnant. As Hydrosychidae require water rich in phytoplankton, a current velocity of 0.6-1.0 m/s was recommended. At Sites 2 and 3, the target flow-dependent species were in the order Odonata, the dragonflies. Nymphs of these species are favoured by low flow conditions that foster prey species and provide protection from aquatic predators. In contrast, adults rely on marginal vegetation and are favoured by periodic inundation of the banks. High flows are also necessary for drift to promote recolonization of disturbed biotopes in order to increase diversity in general. At Site 4, base flow velocities of 0.05-0.15 m/s and high flow velocities of 0.2-0.3 m/s were recommended to sustain Teloganodidae, Tricorythidae and Hydropsychidae. At Site 5, the presence of three additional families of sensitive species (Heptageniidae, Oligoneuridae and Perlidae) necessitated slightly higher velocities, from 0.08-0.20 m/s during base flows and 0.25-0.30 during high flows.

Image 8: The Mara river is the natural habitat for more than 15 species of fish

Objectives

Fish are important indicators of environmental flows because discharge is the primary determinant of their productivity. Because they are more long-lived than macroinvertebrates, they can serve as integrated signals of the health of the river over a period of years. They are also one of the features of rivers most commonly observed and utilized by communities, so changes in their occurrence and abundance may be noticed more readily, and the health of fish populations may be directly important to the health of human communities nearby. The primary objectives of the fish survey were 1) describe and quantify fish communities at each site, 2) determine population structure of critical species, 3) assess species' dependence on flow level, and 4) identify species of conservation significance and invasive or introduced species (Tamatamah 2007, 2012; GLOWS 2011).

Methods

In surveys conducted in 2007 at Sites 1-3, fish were surveyed using gillnets placed in riffles, runs and pools for a standardized period of time. In 2009, Sites 1-3 were re-surveyed at low flows using a combination of gill nets set in deeper sections of the river and a backpack electroshocker used in shallower sections. In 2012, Sites 4-5 were surveyed using gill nets in deeper sections and a seine net and electroshocker in shallower sections.

During all assessments, fish were identified in the field using taxonomic guides, and length, weight and reproductive condition were measured. Catch per unit effort (CPUE, number of fish captured/hour) and relative abundance and distribution of each taxa were determined, and the Shannon-Wiener Diversity Index (H') was calculated for each site. Fish species were also characterized according to their environmental guild, a classification system that groups species that respond similarly to changing hydrology and geomorphology (Welcomme et al. 2006).

Results

In 2007, surveys at Sites 1-3 yielded 110 specimens belonging to 4 families and 6 species, including the four previously documented species in the upper Mara. In 2009, surveys at the same sites and Site 1.2 documented 229 individuals from 6 families and 14 species, more than doubling the number of species captured during the 2006-07 sampling event, and increasing the total number of fish species described from the Mara River to 15. This increase in documented diversity was likely due to use of an electroshocker in addition to gillnets during sampling. In 2012, surveys at Sites 4-5 captured 345 individuals from 9 families and 18 species, including 7 species not previously recorded in the lower reaches of the river. The total number of species documented in the Mara by EFA field assessments is 25 (Table 8). Including data from previous fish surveys conducted in the Tanzanian reaches of the Mara River increases the total number to 34 (Wandera et al. 2004, Chitamwebwa 2007, Tamatamah et al. 2010).

Among the resident fish species in the Mara, two species recorded in this study, *Synodontis victoriae* and *Labeo victorianus*, are native to the Lake Victoria basin and therefore have high conservation priority. Three more species recorded from other studies conducted in the lower Mara (Wandera et al. 2004, Chitamwebwa 2007) are listed as critically endangered, endangered, and near threatened in the IUCN Red List (IUCN 2010). Furthermore, reaches of the Mara River near Lake Victoria have been documented to provide critical refugia to native species of fish suffering severe population declines in Lake Victoria due to introduction of non-native species, overfishing and eutrophication (Katunzi 2003). These data further emphasize the conservation significance of environmental flows in the Mara River.

Table 8: Fish species documented in the Mara River at EFA sites and their classifications into different ecological guilds

Family	Species	Ecological Guild	Site 1	Site 1.2	Site 2	Site 3	Site 4	Site 5
CYPRINIDAE (Minnows and Carps)	*Labeo victorianus*	Lotic	a		a	a	a	a
	Labeo cylindricus	Lotic	a		a	a		a
	Barbus oxyrhynchus	Pool	a		a			
	Barbus altianalis	Pool	a		a	a	a	a
	Barbus paludinosus	Pool	a			a		a
	Barbus cercops	Pool				a		
	Barbus kerstenii	Pool			a			
CLARIDAE (Airbreathing catfish)	*Clarias liocephalus*	Lotic	a	a				
	Clarias gariepinus	Eurytopic			a	a	a	a
	Clarias alluaudi	Eurytopic					a	a
MORMYRIDAE (Elephant fishes)	*Mormyrus kannume*	Eurytopic			a	a	a	
	Petrocephalus catostoma	Eurytopic						a
	Hippopotamyrus grahami	Eurytopic						a
	Gnathonemus longibarbis	Eurytopic						a
BAGRIDAE (Bagrid catfishes)	*Bagrus docmac*	Eurytopic			a		a	a
SHILBEIDAE (Shilbeid catfishes)	*Shilbe mystus*	Lotic						a
MOCHOKIDAE (Squeakers)	*Chiloglanis somereni*	Riffle			a	a		
	Synodontis victoriae	Eurytopic						a
	Synodontis afrofischeri	Eurytopic						a
CICHLIDAE (Cichlids)	*Tilapia zillii*	Eurytopic				a		
	Haplochromis sp.	Eurytopic				a		
	Oreochromis sp.	Eurytopic	a					
	Oreochromis niloticus	Eurytopic						a
CHARACIDAE (African tetras)	*Brycinus sadleri*	Pool						a
MASTACEMBELIDAE (Spiny eels)	*Afromastacembelus frenatus*	Lentic						a

Across Site 1-3, in both 2007 and 2009, the dominant species were Barbus altianalis (41%) and Clarias liocephalus (25%), followed by Labeo victorianus (15%) and L. cylindricus (14%).

However, Labeo constituted the majority of the biomass (54%). At Sites 4 and 5, the dominant species were in the family Cyprinidae (64%). Two small species of Barbus (B. paludinosus and B. oxyrhynchus) were the most abundant followed by Labeo victorianus.

Catch per unit effort (CPUE, # individuals/hour) was used as an indicator of relative abundance across the EFA sites (Table 9). Sites 1 and 2 had fairly high CPUE, particularly with electroshocking. Site 1.2 had fairly low CPUE for both gillnets and electroshocker because of the low abundance of C. liocephalus, which is the only species occurring at the site likely due to a dam and natural waterfall just downstream of the study site that prevents upstream migration of other fish species. Site 3 also had low CPUE, although low sampling success could have been due to sampling challenges from large wildlife and channel incision that made thorough sampling difficult. Sites 4 and 5 had higher CPUE with gillnets than any other site except Site 1, although they had lower CPUE with the electroshocker.

Diversity generally increased from upstream to downstream. Site 5 had the highest species diversity, followed by Sites 3 and 2. Site 4 had lower diversity than expected, possibly due to significant alterations to channel structure that affected in-stream habitat. Site 1 had slightly lower values than Site 4. Site 1.2, at which only one species, C. liocephalus, was documented, had a diversity index value of 0.

Table 9: Catch per unit effort, as an indicator of abundance, and Shannon-Wiener Diversity Index values for fish surveys at EFA sites*

EFA Site	Catch Per Unit Effort (gill nets)	Catch Per Unit Effort (electroshocker)	Shannon-Wiener Diversity Index
Site 1	5.3	118	1.38
Site 1.2	0.3	66	0
Site 2	3.3	154	1.84
Site 3	2.7	52	1.87
Site 4	5.2	21	1.47
Site 5	14.5	69	2.10

*Data for Sites 1-3 are from the 2009 field assessment

Upon capture fish were examined for their reproductive status. In 2007, about 50% of the adult individuals of the most numerous fish species in the Mara River— *Barbus*, *Labeo* and *Mormyrus*—were carrying ripe gonads, which indicates reproductive activity. In all species there were more adult individuals carrying ripe gonads in March 2007 than July 2007, suggesting higher flow levels triggered reproduction in these species. In 2009, 14 of the 15 species and over 23% of all adults carried ripe gonads. There also were a relatively large number of immature and juvenile fishes present, as well as males and females with recently spent gonads, suggesting the short rains that occurred in December 2008 and January 2009 had been sufficient to trigger spawning activity. In 2009, about 57% of adult individuals captured at Sites 4 and 5 had ripe gonads, and more adults had ripe gonads in February 2012 than May 2012. This data combined with the capture of large numbers of spawning/spent females in February 2012 suggests that spawning may have been associated with floods from the first rains that fell in December 2011/January 2012.

In this system gonadal maturation appears to be cued by first rains and the rising water levels, increased turbidity and temperature decreases that accompany them. Spawning triggered by early spring rains may allow these populations to rapidly colonize newly formed water bodies that are temporarily connected to the main channel, and it may allow migratory spawners, such as *Labeo*, the necessary flow levels to move to upstream nurseries. It is common for many fish species in the tropics to time their spawning to coincide with rising flows and floods, emphasizing the importance of these hydrological events in an environmental flow prescription.

To determine flow requirements needed to sustain the fish component of the river system, fish species were characterized according to their ecological guild (Welcomme et al. 2006). The ecological guild classification approach used in this study grouped fish species according to preferred habitat requirements at various stages of their life cycles and how they are likely to respond to changing hydrology and geomorphology of the river. Fish in the Mara comprise two major communities, each consisting of different guilds (Table 10). Rhithronic communities include the riffle guild and the pool guild. Potamonic communities include the lotic guild (longitudinal migrants), lentic guild (floodplain migrants) and eurytopic guild (tolerant of low dissolved oxygen). Riffle, pool and lotic guilds are most sensitive to changes in the flow regime that affect habitat availability, dissolved oxygen levels and mobility. Thus, species representing these communities are the best indicators of a suitable flow regime.

Table 10: Representative fish species in major environmental fish guilds in the Lower Mara River

Fish community type	Ecological guild	Representative fish genera/ species in the Mara River	Sensitivity to flow
Rhithronic communities	Riffle guild	*Chiloglanis*	Critical
	Pool guild	Small cyprinids (*Barbus paludinosus, B. amphigramma, B. kerstenii*); Small characins (*Brycinus jacksonii* and *B. sadleri*)	Moderate
Potamonic communities	Lotic guild	Large cyprinids (*Labeo victorianus, Barbus altianalis* and *B. oxyrhynchus*); Schilbeid and airbreathing catfish (Schilbe intermedius, Clarias liocephalus)	High
	Lentic guild	Protopterus; Spiny eel (*Afromastacembelus frenatus*)	Low
	Eurytopic guild	*Clarias gariepinus*, *Tilapia*, *Oreochromis*, Haplochromines (*Astatotilapia* and *Haplochromis* spp), Mormyrids (*Mormyrus* and *Petrocephalus*), *Synodontis*, *Ctenopoma*	Low

Flow Recommendations

Flow recommendations for fish are needed to allow survival during low flows and mobility and reproduction during high flows. Base flows were prescribed for all sites to maintain sufficient dissolved oxygen levels and depth for survival. High flows were prescribed to inundate benches and floodplains, promote nutrient transfer to the river, cue spawning and allow upstream migration. Recommendations at all sites were made for the most flow-sensitive species, as these recommendations would be suitable for all other species present.

At Sites 1, 3 and 4, *Labeo* was the most sensitive species documented, requiring a threshold depth to allow upstream migration of the larger-bodied members of these species. At Site 2, *Chiloglanis* was the most sensitive species, requiring sufficient depth to inundate at least 50% of riffle habitat and at least 0.3 m/s velocity during most life phases. At Site 5, Labeo was the most sensitive species, although breeding requirements of Mormyrids such as *Hippopotamyrus*, which spawn by attaching eggs to emergent vegetation, require additional flow considerations. Sufficient depth was prescribed to maintain critical in-channel habitat that provided emergent vegetation.

Flow Setting Workshop

Classification of Sites: Ecological Management Category

The EFA Team, including specialists and resource managers, met in October, 2007, and July, 2012, to determine the recommended reserve flows for Sites 1-3 and Sites 4-5, respectively. To assist in determining necessary flow levels, the team of specialists first ranked physical and biological components at each site according to their present and desired ecological state. Present Ecological State (PES) recognizes the natural, or reference, conditions at each site and includes a judgment of how far each site has changed from those conditions. Sites could be ranked from A (natural) to F (critical/extremely modified). Then sites were assigned a Trajectory of Change, indicating whether each component was getting better or worse under the current river management regime. Sites were also classified according to their Ecological Importance and Sensitivity (EIS), indicating their importance for maintenance of ecological diversity and system functioning on local and wider scales, their ability to resist disturbance and their capability to recover from disturbance. Finally, sites were assigned an Ecological Management Category (EMC), summarizing the overall objective or desired state for each site. Sites could be ranked from A (natural) to D (largely modified); categories E and F were excluded from consideration because they were not considered sustainable.

Although categories varied somewhat among specialists and sites, the summary for all five sites was very similar

Table 11). The PES at all study sites except Site 4 was ranked as B, indicating a low degree of modification from the natural state. Site 4 was ranked as B/C, indicating a more moderate degree of modification from natural conditions has occurred at this site. All sites were found to be declining in quality under the current management regime. This is cause for concern, as all sites were also ranked High or Very High in their EIS. Pristine conditions are not likely to be achievable in this system given its importance to the local communities; however, due to the high ecological importance of the system, an EMC of category B was chosen for each site. This EMC guided specialists' recommendations for reserve flows and the balance sought between water for ecological function and that for extractive uses. This EMC also suggests management actions should aim to maintain or improve current levels of system structure and functioning and prevent further modification and degradation.

Table 11: Recommended ecological management categories for EFA sites

Site	Present Ecological State	Trajectory of Change	Trajectory of Change	Recommended Ecological Management Category
Site 1	B	Declining	Very High	B
Site 2	B	Declining	Very High	B
Site 3	B	Declining	Very High	B
Site 4	B/C	Declining	High	B
Site 5	B	Declining	High	B

Determining Reserve Flows

Using the EMC as a guide, each specialist presented the necessary flow requirements for his or her component of the river system for each of the environmental flow building blocks (Appendix 1). Specialists explained their motivations for all flow requirements and described the potential consequences of not meeting the requirement. The hydraulics specialist converted these flow requirements to discharge amounts, and the hydrologist ensured they were in line with the historical hydrological record. During the process, a consensus was sought among the specialists of the minimum flows and floods that would suffice to achieve the EMC for each site. Based on the specialists' recommendations for average flows during key months of the year, the hydrologist extrapolated these recommendations across the entire year in a manner that simulated the natural shape of the river's historical hydrograph. The modified hydrograph, with associated floods, serves as the recommended reserve flow. These reserve flow recommendations were compared with the historical hydrograph for each site in order to determine the amount of water available for extractive use.

Reserve Flow Recommendations

Reserve flow recommendations for Sites 1-3 were updated in line with methods used for Sites 4-5. Although the specialists' recommendations for critical flows at these sites did not change from those presented in the initial EFA report, the normal and drought year hydrographs used to extrapolate these flows and determine the amount remaining for extraction changed somewhat based on updated hydrological records and the more robust use of hydrometeorological indices to determine drought flows.

At Site 1 on the Amala River, the maintenance year reserve flows account for a total of 28% of mean annual runoff and are exceeded on average 66% of the time. Average available discharge exceeds maintenance year reserve flows during all months, leaving water available for extraction, although less is available from November through March. Drought year reserve flows account for 7% of mean annual runoff and are exceeded on average 89% of the time. Drought year reserve flows exceed available discharge from January to March, but water is available for extraction in other months.

At Site 2, just below the confluence of the Amala and Nyangores, maintenance year reserve flows account for 40% of mean annual runoff and are exceeded on average 73% of the time. Average available discharge exceeds maintenance year reserve flows in all months, leaving water for extraction, although less is available from November to March. Drought year reserve flows account for 13% of mean annual runoff and are exceeded on average 91% of the time. Drought year reserve flows exceed available discharge in February and March, but water is available for extraction in other months.

At Site 3, on the border between Kenya – Tanzania and Masai Mara National Reserve – Serengeti National Park, maintenance year reserve flows account for 45% of mean annual runoff and are exceeded on average 61% of the time. Average available discharge exceeds maintenance year reserve flows throughout the year, leaving sufficient water available for extraction. Drought year reserve flows account for 15% of mean annual runoff and are exceeded on average 86% of the time. Drought year reserve flows only exceed available discharge slightly in November, although very little water is available for extraction throughout the rest of the year.

At Site 4, inside the Serengeti National Park, maintenance year reserve flows account for a total of 54% of mean annual runoff and are exceeded on average 61% of the time. Maintenance year reserve flows exceed average available discharge over all months, leaving sufficient water available for extraction. Drought year reserve flows account for 11% of mean annual runoff and are exceeded on average 86% of the time. Drought year reserve flows only exceed available discharge slightly in November, but more water is available for extraction from March to September.

At Site 5, near Mara Mines in Tanzania, maintenance year reserve flows account for a total of 42% of mean annual runoff and are exceeded on average 61% of the time. Maintenance year reserve flows exceed average available discharge over all months, leaving sufficient water available for extraction. Drought year reserve flows account for 8% of mean annual runoff and are exceeded on average 86% of the time. Similar to Site 4, drought year reserve flows only exceed available discharge slightly in November, but more water is available for extraction from March to September.

Following are the results for the recommended average monthly reserve flows and flood events for both maintenance and drought years, for each of the five sampling sites. These results are presented in both tabular format, which provide a month by month prescription to be used by water resource managers, as well as graphically. Maintenance year reserve flows are shown in comparison to average monthly flow recorded over the length of record, and drought year reserve flows are shown in comparison to average drought year discharge, as indicated by hydrometeorological indices.

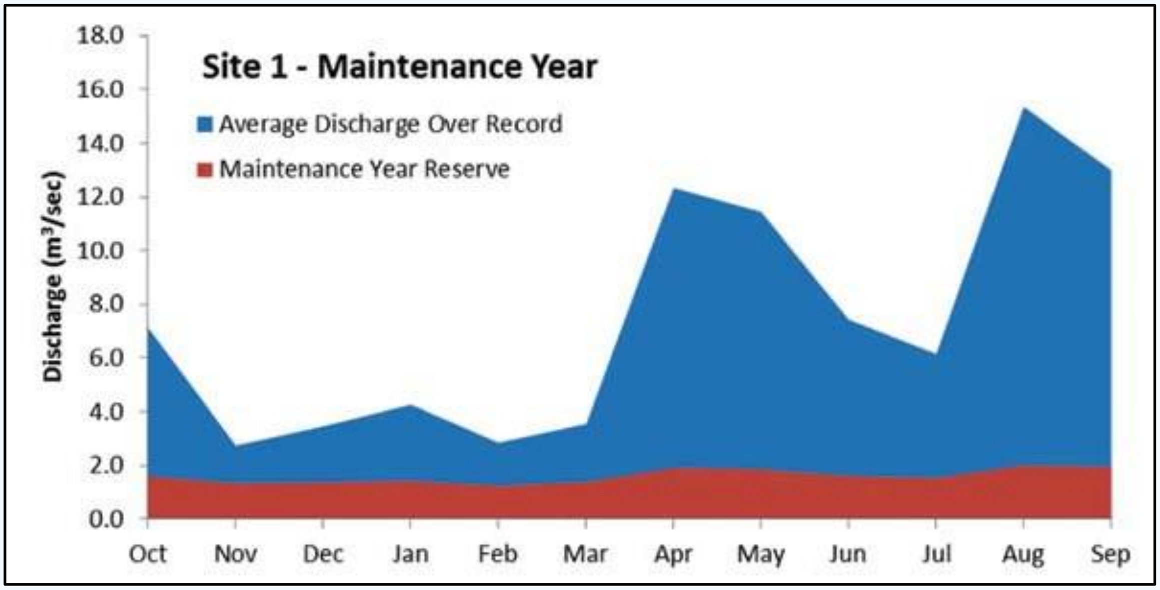
Table 12: Environmental flow requirements for Site 1 in the upper Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff

Building Blocks		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Maintenance EFR Base Flows	Magnitude (m^3/s)	1.60	1.34	1.38	1.43	1.25	1.39	1.92	1.86	1.62	1.54	2.00	1.95
	Depth (m)	0.35	0.32	0.33	0.33	0.31	0.33	0.38	0.37	0.35	0.34	0.38	0.38
	Volume (MCM)	4.29	3.47	3.70	3.83	3.02	3.72	4.96	4.99	4.20	4.14	5.36	5.06
	FDC % present	67%	68%	71%	71%	71%	71%	63%	59%	65%	65%	57%	59%
Higher Flows	Magnitude (m^3/s)							12	12			38	12
	Depth (m)							0.84	0.84			1.40	0.84
	Duration (d)							2	2			2	2
	Return Period (y)							1	1			1	1
	Volume (MCM)							2.07	2.07			6.57	2.07
	FDC % present							17%	17%			4%	17%
Drought EFR Base Flows	Magnitude (m^3/s)	0.36	0.55	0.35	0.24	0.30	0.22	0.42	0.80	0.44	0.42	0.82	1.00
	Depth (m)	0.18	0.22	0.18	0.15	0.17	0.15	0.19	0.26	0.20	0.19	0.26	0.28
	Volume (MCM)	0.96	1.41	0.92	0.64	0.73	0.60	1.09	2.13	1.15	1.12	2.19	2.59
	FDC % present	92%	87%	92%	95%	94%	96%	90%	81%	89%	90%	80%	76%
Higher Flows	Magnitude (m^3/s)												4
	Depth (m)												0.52
	Duration (d)												1
	Return Period (y)												1
	Volume (MCM)												0.35
	FDC % present												40%

Maintenance EFR	Base Flows	Higher Flows	Toatal	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	50.75	12.79	63.54		15.53	0.35	15.88
as % of MAR	22.2%	5.6%	27.8%		6.8%	0.15%	6.9%
MAR (MCM)	228.81						

Figure 16: EFA recommendations at Site 1 for a) average discharge over period of record and maintenance year reserve flows, and b) average drought year discharge and drought year reserve flows

a.



b.

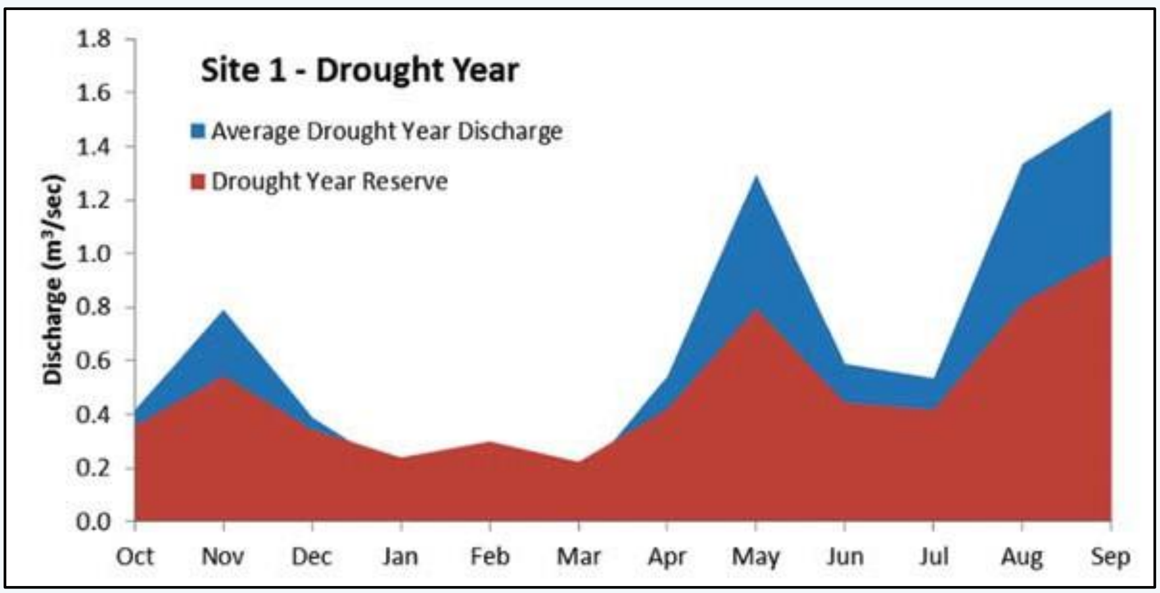


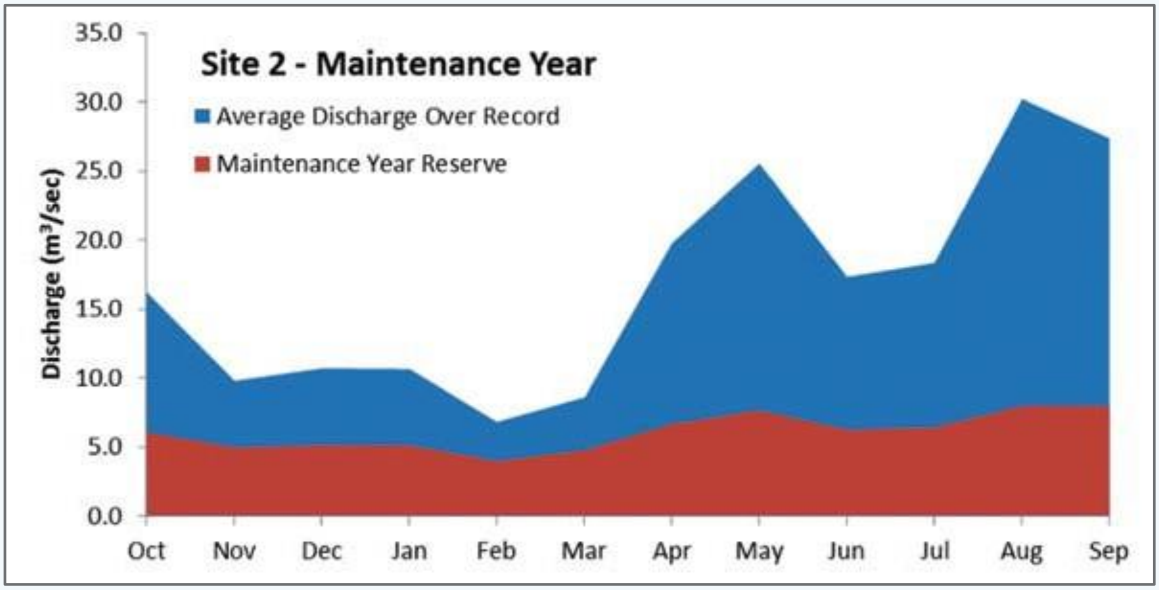
Table 13: Environmental flow requirements for Site 2 in the middle Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff

Building Blocks		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Maintenance EFR Base Flows	Magnitude (m^3/s)	6.09	4.99	5.15	5.14	4.00	4.79	6.70	7.68	6.28	6.45	8.00	8.00
	Depth (m)	0.39	0.36	0.37	0.37	0.34	0.36	0.40	0.42	0.39	0.40	0.43	0.43
	Volume (MCM)	16.32	12.94	13.79	13.77	9.68	12.83	17.37	20.58	16.28	17.29	21.43	20.73
	FDC % present	74%	76%	77%	80%	80%	80%	71%	65%	70%	70%	63%	66%
Higher Flows	Magnitude (m^3/s)								16	16	16	75	
	Depth (m)								0.54	0.54	0.54	0.93	
	Duration (d)								1	1	1	3	
	Return Period (y)								1	1	1	1	
	Volume (MCM)								1.38	1.38	1.38	19.44	
	FDC % present								38%	38%	38%	1%	
Drought EFR Base Flows	Magnitude (m^3/s)	2.21	1.96	1.47	1.11	0.98	1.00	1.58	2.12	2.03	2.76	3.67	4.00
	Depth (m)	0.27	0.26	0.24	0.21	0.21	0.21	0.24	0.27	0.26	0.29	0.33	0.34
	Volume (MCM)	5.92	5.09	3.95	2.97	2.36	2.68	4.09	5.69	5.26	7.38	9.83	10.37
	FDC % present	89%	91%	96%	97%	98%	98%	92%	89%	86%	87%	84%	81%
Higher Flows	Magnitude (m^3/s)								25				
	Depth (m)								0.64				
	Duration (d)								2				
	Return Period (y)								1				
	Volume (MCM)								4.32				
	FDC % present								23%				

Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	193.00	23.59	216.59		65.57	4.32	69.89
as % of MAR	35.3%	4.3%	39.6%		12.0%	1.3%	13.3%
MAR (MCM)	546.77						

Figure 17: EFA recommendations at Site 2 for a) average discharge over period of record and maintenance year reserve flows, and b) average drought year discharge and drought year reserve flows

a.



b.

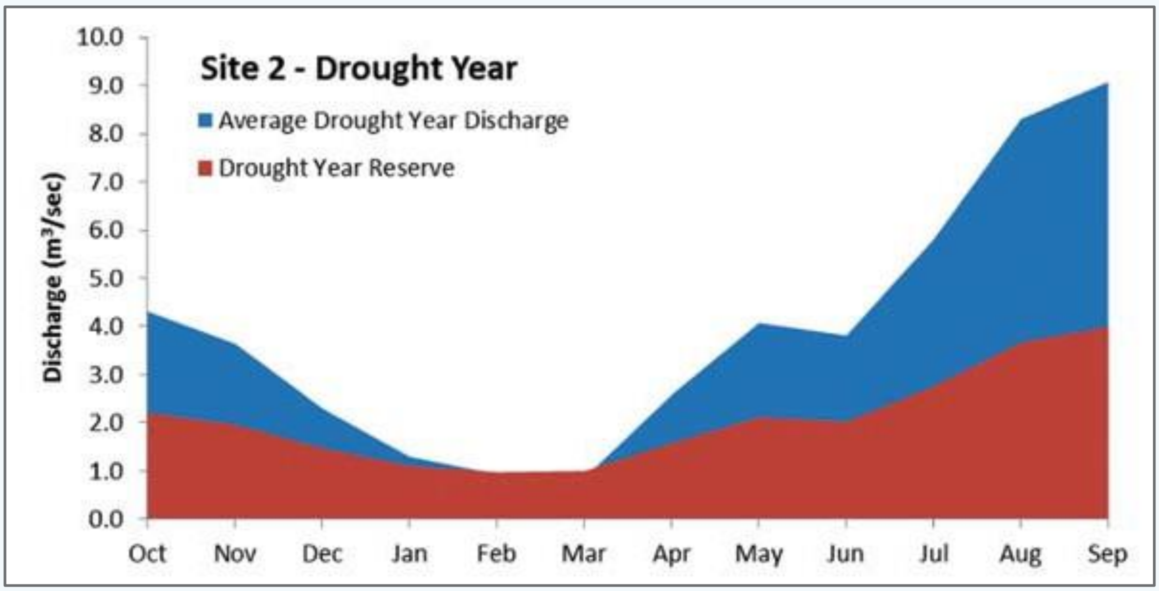


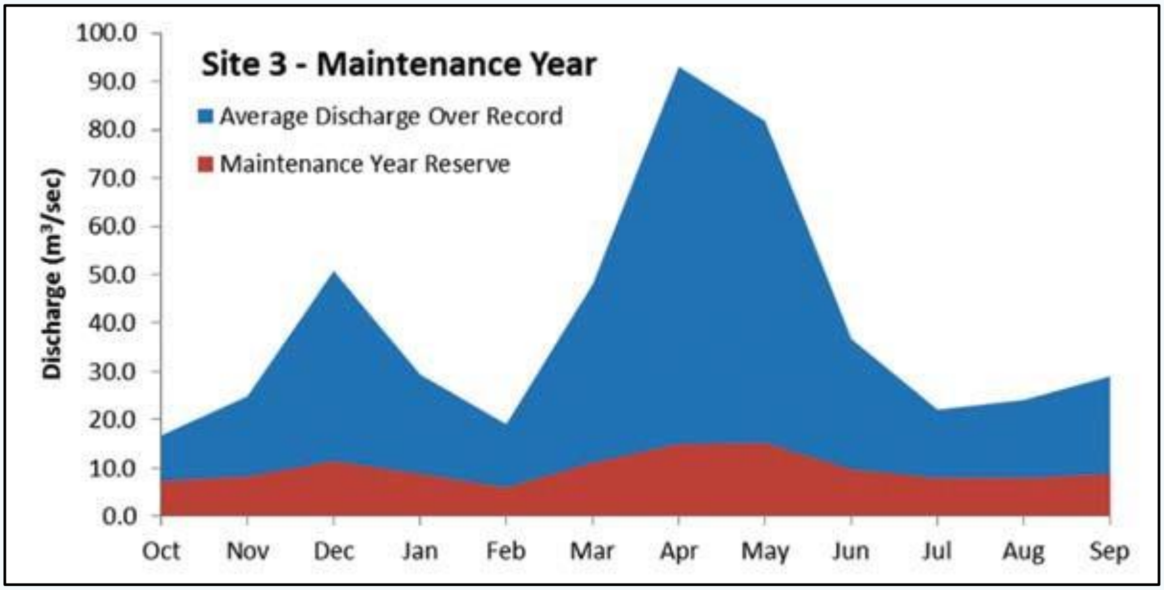
Table 14: Environmental flow requirements for Site 3 in the lower Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff

Building Blocks		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Maintenance EFR Base Flows	Magnitude (m^3/s)	7.31	8.30	11.45	8.85	6.00	11.11	15.00	15.23	9.74	7.96	7.96	8.80
	Depth (m)	0.66	0.69	0.79	0.71	0.61	0.78	0.88	0.88	0.74	0.68	0.68	0.71
	Volume (MCM)	19.57	21.51	30.67	23.69	14.52	29.77	38.88	40.78	25.25	21.32	21.32	22.81
	FDC % present	68%	68%	61%	60%	70%	61%	45%	51%	58%	63%	63%	60%
Higher Flows	Magnitude (m^3/s)							90	25	25	25		
	Depth (m)							1.77	1.07	1.07	1.07		
	Duration (d)							3	2	2	2		
	Return Period (y)							1	1	1	1		
	Volume (MCM)							23.33	4.32	4.32	4.32		
	FDC % present							7%	26%	26%	26%		
Drought EFR Base Flows	Magnitude (m^3/s)	2.74	1.75	2.43	3.05	2.00	4.03	5.13	6.00	3.24	3.47	5.70	4.05
	Depth (m)	0.45	0.38	0.43	0.47	0.40	0.52	0.58	0.61	0.48	0.49	0.60	0.52
	Volume (MCM)	7.35	4.54	6.52	8.18	4.84	10.79	13.30	16.07	8.39	9.29	15.27	10.50
	FDC % present	95%	97%	97%	95%	92%	85%	74%	70%	82%	85%	74%	83%
Higher Flows	Magnitude (m^3/s)								20				
	Depth (m)								0.98				
	Duration (d)								2				
	Return Period (y)								1				
	Volume (MCM)								3.46				
	FDC % present								36%				

Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	310.07	36.29	346.36		115.04	3.46	118.49
as % of MAR	39.8%	4.7%	44.5%		14.8%	0.4%	15.2%
MAR (MCM)	778.24						

Figure 18: EFA recommendations at Site 3 for a) average discharge over period of record and maintenance year reserve flows, and b) average drought year discharge and drought year reserve flows

a.



b.

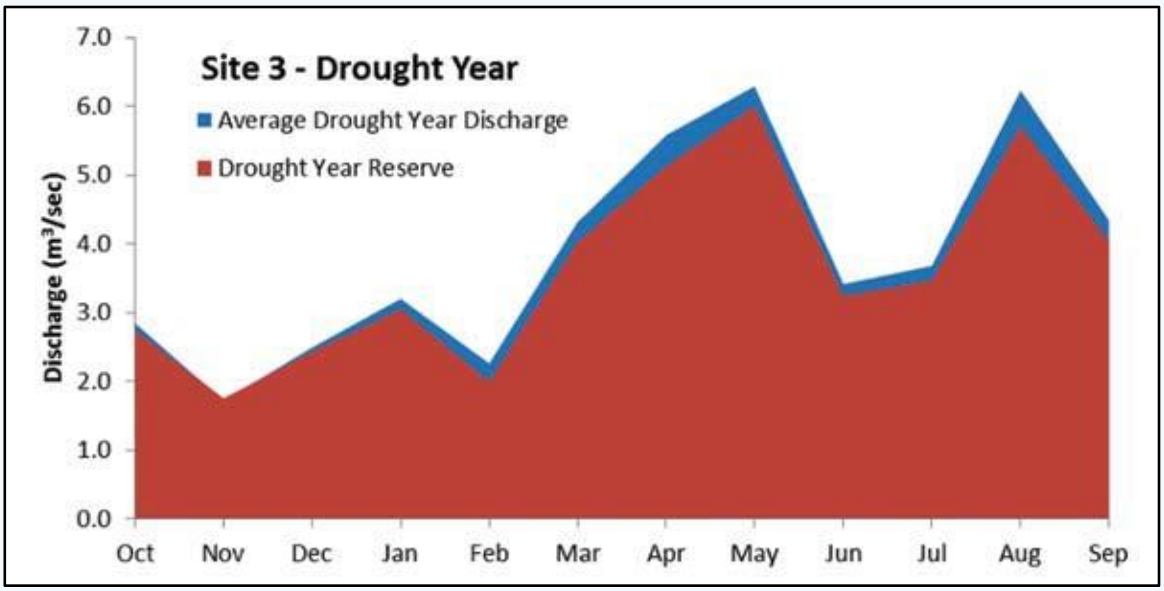


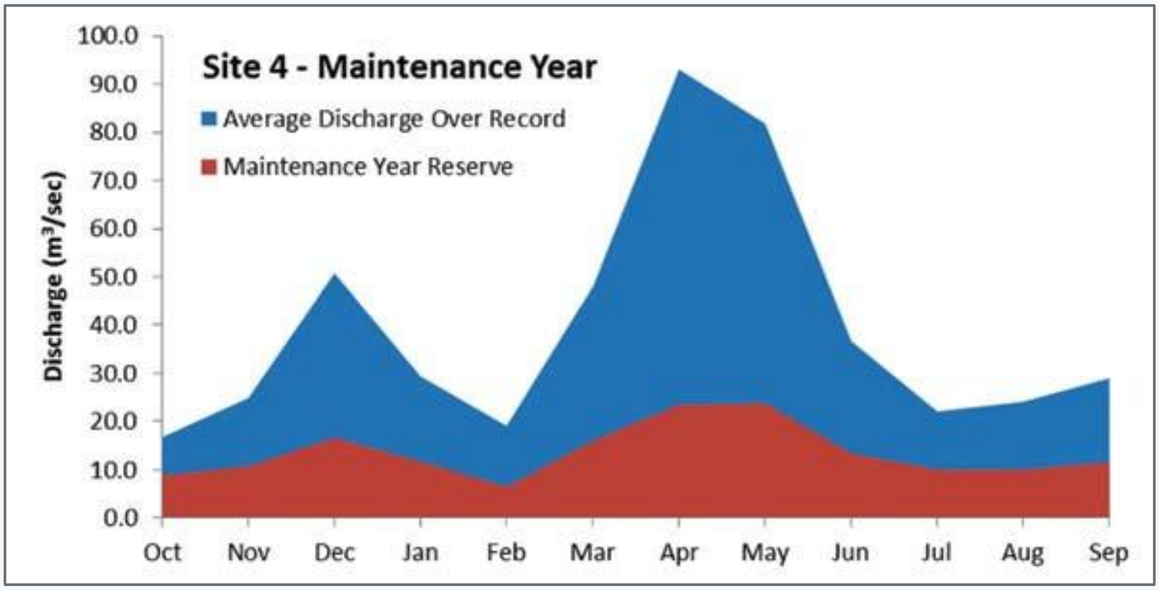
Table 15: Environmental flow requirements for Site 4 in the lower Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff

Building Blocks		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Maintenance EFR Base Flows	Magnitude (m^3/s)	8.85	10.73	16.68	11.76	6.50	16.04	23.50	23.81	13.45	10.09	10.09	11.67
	Depth (m)	0.35	0.39	0.50	0.41	0.29	0.49	0.61	0.61	0.44	0.37	0.37	0.41
	Volume (MCM)	23.72	27.80	44.67	31.50	15.72	42.97	60.91	63.78	34.86	27.01	27.01	30.26
	FDC % present	68%	68%	61%	60%	70%	61%	45%	51%	58%	63%	63%	60%
Higher Flows	Magnitude (m^3/s)			367				535					
	Depth (m)			2.89				3.58					
	Duration (d)			1				1					
	Return Period (y)			1.8				2.3					
	Volume (MCM)			31.71				46.22					
	FDC % present			1%				1%					
Drought EFR Base Flows	Magnitude (m^3/s)	2.56	1.81	2.32	2.79	2.00	3.52	4.35	5.00	2.93	3.10	4.78	3.54
	Depth (m)	0.17	0.14	0.16	0.18	0.15	0.21	0.23	0.25	0.19	0.19	0.24	0.21
	Volume (MCM)	6.85	4.70	6.23	7.47	4.84	9.43	11.27	13.39	7.59	8.31	12.79	9.17
	FDC % present	95%	97%	97%	95%	92%	85%	74%	70%	82%	85%	74%	83%
Higher Flows	Magnitude (m^3/s)								10				
	Depth (m)								0.37				
	Duration (d)								1				
	Return Period (y)								1				
	Volume (MCM)								0.86				
	FDC % present								65%				

Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	430.23	77.93	508.16		102.04	0.86	102.91
as % of MAR	45.7%	8.3%	54.0%		10.8%	0.1%	10.9%
MAR (MCM)	941.36						

Figure 19: EFA recommendations at Site 4 for a) average discharge over period of record and maintenance year reserve flows, and b) average drought year discharge and drought year reserve flows

a.



b.

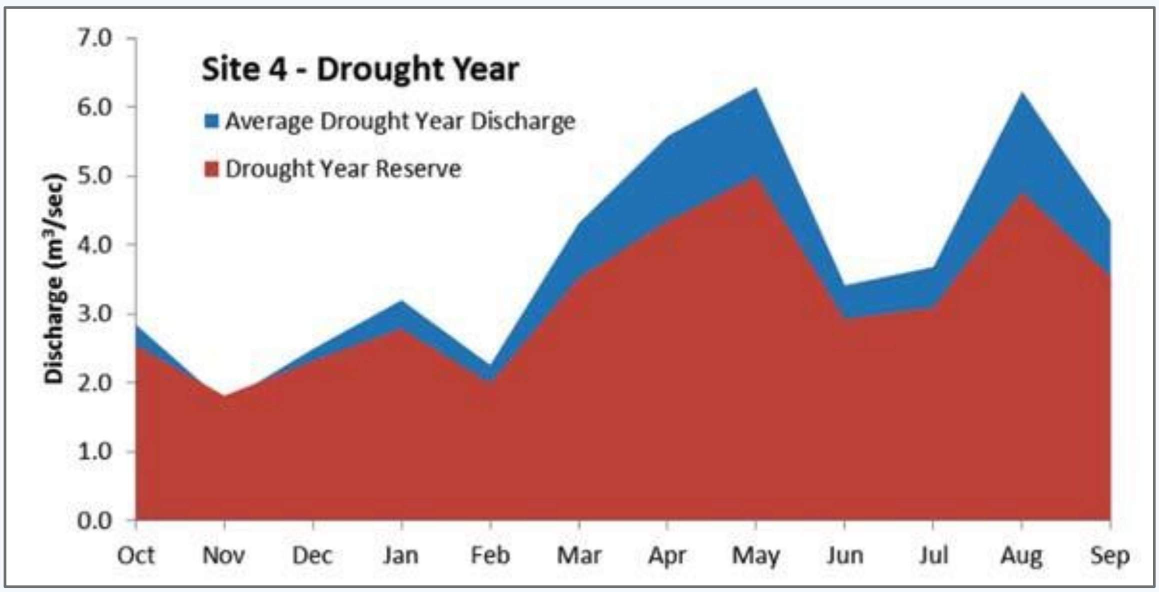


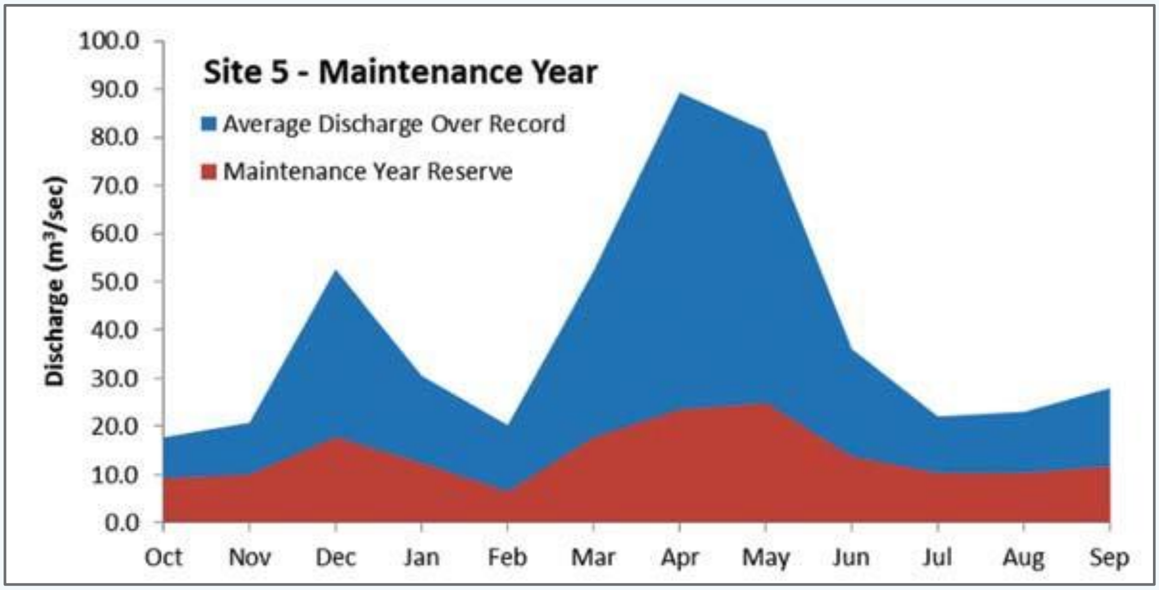
Table 16: Environmental flow requirements for Site 5 in the lower Mara River Basin. FDC- Flow Duration Curve; MCM- million cubic meters; MAR- median annual runoff

Building Blocks		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Maintenance EFR Base Flows	Magnitude (m^3/s)	9.28	10.02	17.85	12.43	6.50	17.80	23.50	24.92	13.80	10.34	10.34	11.79
	Depth (m)	0.55	0.57	0.77	0.64	0.46	0.77	0.88	0.91	0.67	0.58	0.58	0.62
	Volume (MCM)	24.85	25.97	47.82	33.29	15.72	47.67	60.91	66.75	35.76	27.71	27.71	30.57
	FDC % present	68%	68%	61%	60%	70%	61%	45%	51%	58%	63%	63%	60%
Higher Flows	Magnitude (m^3/s)			367				535					
	Depth (m)			3.60				4.37					
	Duration (d)			1				1					
	Return Period (y)			1.8				2.3					
	Volume (MCM)			31.71				46.22					
	FDC % present			3%				1%					
Drought EFR Base Flows	Magnitude (m^3/s)	2.59	2.00	2.35	2.84	2.00	3.62	4.50	5.00	2.99	3.17	4.14	3.64
	Depth (m)	0.29	0.25	0.27	0.30	0.25	0.34	0.38	0.40	0.31	0.32	0.36	0.34
	Volume (MCM)	6.95	5.19	6.28	7.61	4.84	9.70	11.67	13.39	7.75	8.50	11.09	9.43
	FDC % present	95%	97%	97%	95%	92%	85%	74%	70%	82%	85%	74%	83%
Higher Flows	Magnitude (m^3/s)								10				
	Depth (m)								0.57				
	Duration (d)								1				
	Return Period (y)								1				
	Volume (MCM)								0.86				
	FDC % present								72%				

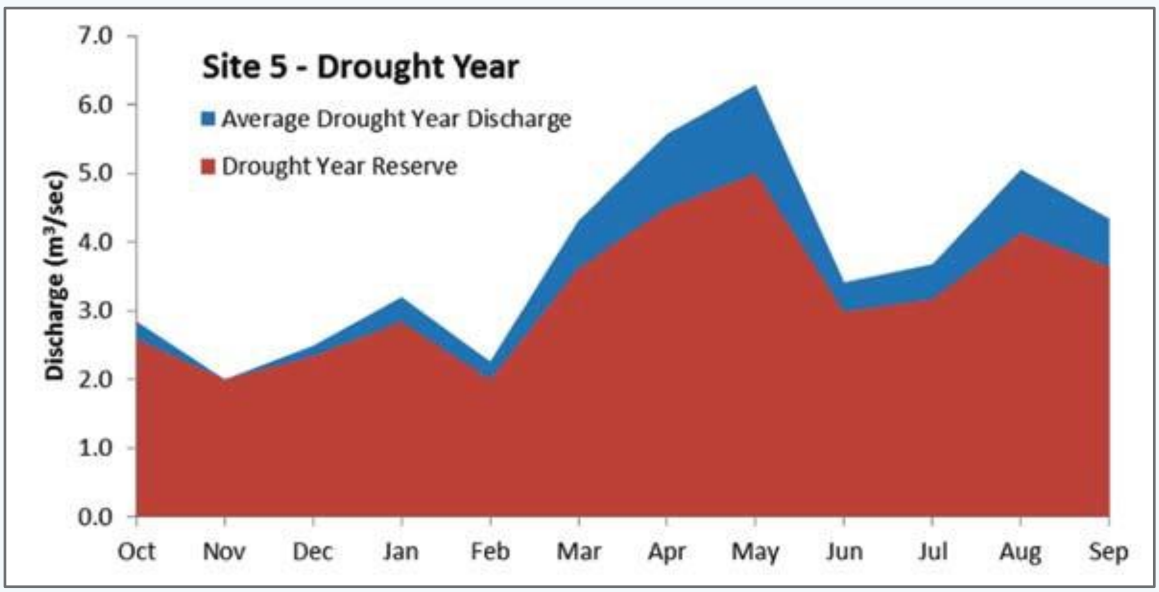
Maintenance EFR	Base Flows	Higher Flows	Total	**Drought EFR**	Base Flows	Higher Flows	Total
Volume (MCM)	444.73	77.93	522.66		102.41	0.86	103.28
as % of MAR	35.4%	6.2%	41.6%		8.2%	0.1%	8.3%
MAR (MCM)	1255.7						

Figure 20: EFA recommendations at Site 5 for a) average discharge over period of record and maintenance year reserve flows, and b) average drought year discharge and drought year reserve flows

a.



b.



Implementation of Findings

Development of EFRs for sites throughout the entire Mara River Basin is a great achievement, but the utility of this report will only be fully realized when these recommendations are implemented on the ground. During the final flow setting workshop (July 2012), a team of water resource managers, protected areas representatives and stakeholders from both the Kenyan and Tanzanian portions of the basin discussed the primary challenges and opportunities for implementation of the findings of this report, and key recommendations were proposed.

Recommendations

- Use EFA recommendations to determine allowable water extraction permit levels
- Monitor discharge and extraction levels in the river in order to reduce extractions if the reserve is threatened
- Develop small-scale, off-catchment storage capacity to capture high flows for use during low flow periods
- Develop capacity of both water resource managers and community Water Resource User's Associations (KE) and Water User's Associations (TZ) to monitor and protect reserve flows
- Decrease land degradation, particularly in riparian areas, to promote natural water storage and maintain higher flows in dry seasons

Challenges

- Lack of awareness and possibly political will among senior decision-makers and politicians
- Scarcity of data on water quality and quantity in the basin
- Lack of a catchment management strategy in Tanzania, despite the presence of a national strategy
- Limited financial and human capacity
- Limited incorporation of temporary, donor-funded projects into government institutions and actions
- Lack of an agreement between Kenya and Tanzania on use and management of water resources
- Lack of a coordinating body with some legal authority for trans-boundary issues in the Mara
- Lack of information sharing between technical bodies in Kenya and Tanzania
- Low economic status of majority of basin inhabitants often leads to unsustainable resource use

Opportunities

- The reserve is specified and protected in laws and regulations in both countries
- Existence of political will, as demonstrated by restoration of the Mau, in passing and upholding of environmental laws
- EFRs are available for the entire basin
- New institutional structures exist for water resources management which are developed around catchment area
- LVBC serves as a coordinating body in the region
- International interest and support for this initiative
- Sufficient water is still remaining in the river; it is not yet over-allocated
- In Kenya, the Water Resources Management Authority is developing catchment and sub-catchment management plans and undertaking water allocation plans
- In Tanzania, Basin Water Offices are developing Integrated Water Resources Management Plans
- The Lake Victoria Basin Commission is incorporating the EFA findings into a water allocation strategy for the basin
- The East African Community recognizes the importance of trans-boundary water resources management; the Transboundary
- Ecosystem Management Bill was just passed by East Africa Legislative Assembly
- Local stakeholder engagement, as evidenced by WRUAs and WUAs on both sides of the basin, can aid in monitoring and protection of reserve flows
- High level of awareness in the basin and region on the importance of watershed conservation
- Great synergy exists between partners in the basin
- Development of a remarkable network of hydromet stations (17 gauging stations in the basin within the next year), thanks in part to funding from NELSAP, will improve information on water quantity and quality in the basin

Conclusion

This EFA found that there is sufficient water in the Mara River during years of normal rainfall to allow for water extraction throughout the year at all sites. At Site 1 on the Amala River, the recommended Reserve flow levels account for 28% of mean annual runoff during maintenance years. At Site 3 on the border between Kenya – Tanzania and Masai Mara National Reserve – Serengeti National Park, the Reserve accounts for 45% of mean annual runoff. At Site 5, the reserve accounts for an average of 42% of mean annual runoff. It is important to note, however, that the percent of flow held in the reserve varies over the course of a year, mirroring the natural highs and lows of the system. The majority of water available for abstraction is therefore concentrated in the months when flows are highest.

During drought years, the situation is quite different. Recommended reserve flows exceed the historical average flows for three months at Site 1, two months at Site 2, and one month at Sites 3-5, and they leave little water available for extraction during the remaining months, particularly at Sites 1 and 3. The observation that drought year reserve flows, particularly in the upper and middle reaches of the Mara, may be the first clear evidence of a trend toward unacceptable alterations of the Mara River's flow regime. There could be several explanations for the difference between environmental flow recommendations and average drought year flows. First, determination of environmental flows should be an ongoing process that relies on the cautionary principle to protect sufficient minimum flows; however, continued monitoring could reveal that required reserve levels are lower than prescribed here. Second, the prescribed reserve levels could prove to be accurate, but levels of extraction could be unsustainably high during dry seasons of drought years and need to be reduced. Third, prescribed reserve levels could be accurate and abstraction levels could be reasonable, but land-use practices in the basin may have sufficiently altered the hydrograph of the river such that dry season drought year low flows are unnaturally low, suggesting that land rehabilitation in the upper catchment is necessary for the reserve to be restored.

This EFA did not take into account the water needs of the Mara Wetland, which may be different. Additional surveys should be done in that critical ecosystem to ensure sufficient reserve flows are available to maintain its ecosystem function. This EFA is also a living document that should be updated as needed as the river continues to be monitored and determinations are made if sufficient water quantity and quality is being provided to maintain desired ecosystem services.

The recommendations of this EFA have been adopted and recommended for implementation by the Lake Victoria Basin Council of Ministers of the East African Community. The Council of Ministers Meeting provides a powerful opportunity to continue building links between policy makers and practitioners and will provide an important venue for discussing how to implement the recommendations from this and other EFAs in the region.

The current state of the Mara River—still flowing year-round and with generally good water quality—provides an excellent opportunity to protect this river while it is still in good condition. Restoring a river after it has been over-allocated, severely polluted or impounded is exceedingly difficult, and sometimes impossible. The Mara River provides so many critical resources, to the local communities living along it, the wildlife that migrate to drink from its waters and the economies of two countries, that we cannot risk allowing it to decline. Implementing the recommendations of this EFA to protect reserve flows in the Mara River will be a powerful step towards protecting this river for current and future generations.

References

Athuman, M. 2011. Water quality assessment for the lower catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Ayieko, J. 2012. Riparian vegetation assessment for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Chitamwebwa, D. B.R. 2007. A baseline survey of fisheries resources in the Mara Swamp and Musoma Bay, Tanzania.

Defersha, M. B., and A. M. Melesse. 2011. Field-scale investigation of the effect of land use on sediment yield and runoff using runoff plot data and models in the Mara River basin, Kenya. Catena 89:54-64.

Defersha, M. B., and A. M. Melesse. 2012. Watershed scale application of WEPP and EROSION 3D models for assessment of potential sediment source areas and runoff flux in the Mara River Basin, Kenya. Catena 95:63-72.

Department of Water Affairs and Forestry (DWAF). 1996. South African water quality guidelines. Volume 7: Aquatic Ecosystems. Department of Water Affairs and Forestry, Pretoria, South Africa.

Dickens, C.W.S. and M. Graham. 2002. The South African Scoring System (SASS) Version 5 rapid bio-assessment method for rivers. African Journal of Aquatic Sciences 27: 1-10.

Dutton, C.L. 2012. Sediment Fingerprinting in the Mara River: Uncovering Relationships Between Wildlife, Tourism, and Non-Point Source Pollution. MSc Thesis, Yale University, New Haven, Connecticut, USA.

Gereta, E., E. Mwangomo, and E. Wolanski. 2009. Ecohydrology as a tool for the survival of the threatened Serengeti ecosystem. Ecohydrology and Hydrobiology 9:115-124.

Global Water for Sustainability (GLOWS). 2011. Refining reserve flow recommendations for the Mara River, Kenya and Tanzania. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Government of Kenya. 2002. Water Resources Management Act. Government Printer, Nairobi, Kenya.

Government of Kenya. 2007. Water Resources Management Rules. Government Printer, Nairobi, Kenya.

Hoffman, C. M. 2007. Geospatial mapping and analysis of water availability-demand-use within the Mara River Basin. Thesis. Florida International University, Miami, FL, USA.

King, J. M, R. E. Tharme, and M. S. de Villeers (editors). 2000. Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology. Water Research Commission Report No.: TT 131/00. Freshwater Research Unit, University of Cape Town, South Africa.

Lake Victoria Basin Commission (LVBC). 2010. Assessing Reserve Flows for the Mara River. Lake Victoria Basin Commission, Kisumu, Kenya.

Onyango, L. 2007. Socioeconomic assessment for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Mango, L. M. 2010. Modeling the effect of Land use and climate change scenarios on the water flux of the upper Mara River flow, Kenya. MSc Thesis, Florida International University, Miami, Florida, USA.

Mango, L. M., A. M. Melesse, et al. 2011. Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. Hydrology and Earth System Sciences 15: 2245-2258.

Mati, B. M., S. Mutie, et al. 2008. Impacts of land-use/cover changes on the hydrology of the transboundary Mara River, Kenya/ Tanzania. Lakes & Reservoirs: Research & Management 13: 169-177.

Melesse, A. 2007. Hydrological assessment for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Mligo, C. 2012. Riparian vegetation assessment for the lower catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Muthike, J. 2007. Geomorphological assessment for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Mwaipopo, R. 2012. Socioeconomic assessment for the lower catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Mwanakuzi, P. 2012. Geomorphological assessment for the lower catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Ndomba, P. 2007. Hydraulic modeling for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Ndomba, P. 2012. Hydraulic modeling for the lower catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Tamatamah, R.A., S. Mukama, T. B. Suya. 2010. Baseline study on the aquatic environment and fauna of the North Mara Goldmine Project Area. Environmental impact assessment studies for the North Mara Goldmine Project. Barrick Gold.

Tamatamah, R. 2012. Aquatic macroinvertebrate assessment for the lower catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

United Republic of Tanzania. 2002. The Water Policy. Government Printer, Dodoma, Tanzania.

United Republic of Tanzania. 2009. The Water Resource Management Act. Government Printer, Dodoma, Tanzania.

Valimba, P. 2012. Hydrological assessment for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Wandera, S. B., A. A. Asila, A. I. Chande, W. O. Ojwang', G. Namulemo, J. Ojuok, J. D. R. Bayona, W. Mwanja, D. M. Masai, H. A. Muhitu, H. Mrosso, B. S. Musuku, and E. F. Katunzi. 200). Fish Communities. Chapter 7 In P. Kansoma (Ed). Aquatic Biodiversity of Lake Victoria Basin: its conservation and sustainable uses. Lake Victoria Environmental Management Program Series, Kisumu, Kenya.

Wasonga, V. 2007. Aquatic macroinvertebrate assessment for the upper and middle catchment of the Mara River EFA. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA.

Water Quality Baseline Assessment Report (WQBAR), Mara River Basin, Kenya-Tanzania. 2007. Global Water for Sustainability Program, Florida International University, Miami, Florida, USA, 61p.

Welcomme, R.L., A.K.O. Winemiller, and I.G. Cowx. 2006. Fish environmental guilds as a tool for assessment of ecological condition of rivers. River Research and Applications 22: 377–396.

Appendix 1: Environmental Flow Building Blocks

Flow Building Blocks	Definitions	Functions
Drought Year Low Flows	the low flow requirements during the driest month of a drought year	• maintain hydrological connectivity in the system • maintain inundation of critical habitats (eg., riffles) • sustain flow-sensitive species • provide natural variability to maintain diverse species assemblage
Drought Year High Flows	the low flow requirements during the wettest month of a drought year	• maintain active channel flows to inundate benches and sustain emergent vegetation • permit fish passage over obstacles
Maintenance Year Low Flows	the low flow requirements during the driest month of a maintenance year	• provide natural variability to maintain diverse species assemblage
Maintenance Year High Flows	the low flow requirements during the wettest month of a maintenance year	• cue migration and spawning in fishes • inundate macrophytes and emergent vegetation along banks • displace dominant competitors and allow drift of species into new habitats, promoting increases in species diversity • maintain groundwater recharge for riparian species
Small Annual Floods	small pulses of higher flow that occur in the drier months	• cue spawning and migration in fishes • inundate surrounding floodplains to facilitate lateral migration of fauna • facilitate nutrient transfer between floodplains and the river • allow germination and seed dispersal of riparian vegetation • prevent sediment build-up on river bed, thus increasing habitat variability for invertebrates • maintain active channel features • flush out organic matter, thus improving water quality
Major Flood Events	major peaks in the river's flow level that occur at a given recurrence interval	• maintain macro channel features and provide diversity of physical habitats • scour bed of sediment deposits • inundate and recharge larger floodplain, allowing for nutrient transfer

Appendix 2: EFA Participants

Participant Groups	Name and Role	Organization
Kenya Water Resources Management Authority	Margaret Abira, Regional Manager, 2006-12	Lake Victoria South Catchment Area, Water Resources Management Authority
	Reuben Ngessa, Basin Hydrologist, 2006-09	Lake Victoria South Catchment Area, Water Resources Management Authority
Tanzania Basin Water Office	Sariro Mwita, Basin Water Officer, 2006-09	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
	Rayson Muhabuki, Basin Water Officer, 2009-11	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
	Rosemary Rwebugisa, Basin Water Officer, 2011-12	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
	Lusekelo Mwambuli, Basin Hydrologist, 2006-09	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
	Ogoma Mangasa, Basin Hydrologist, 2011-12	Lake Victoria Basin Water Office, Ministry of Water and Irrigation
Protected Areas Representatives	Samson Lenjir, Lead Ecologist, 2006-08	Narok County Council, Maasai Mara National Game Reserve
	James Sindiyo, Narok County Council Chief Warden, 2006-09	Narok County Council, Maasai Mara National Game Reserve
	Brian Heath, Director, 2008-12	Mara Conservancy
	James Wakibara, Lead Ecologist, 2006-09	Serengeti National Park
	Emilian Kihwele, Lead Ecologist, 2011-12	Serengeti National Park
EFA Team	Doris Ombara Okundi, Coordinator, 2006-09	WWF-ESARPO, Mara River Basin Management Initiative
	Elizabeth Anderson, Coordinator, 2011-12	Florida International University, USA
	Leah Onyango, Socioeconomist, 2006-09	Maseno University, Kenya
	Rosemarie Mwaipopo, Socioeconomist, 2011-12	University of Dar es Salaam, Tanzania
	Assefa Melesse, Hydrologist, 2006-09	Florida International University, USA
	Patrick Valimba, Hydrologist 2011-12	University of Dar es Salaam, Tanzania
	Preksedis Ndomba, Hydraulic Engineer, 2006-12	University of Dar es Salaam, Tanzania
	Joseph Muthike, Geomorphologist, 2006-12	Consultant
	Phillip Mwanakuzi, Geomorphologist, 2011-12	University of Dar es Salaam, Tanzania

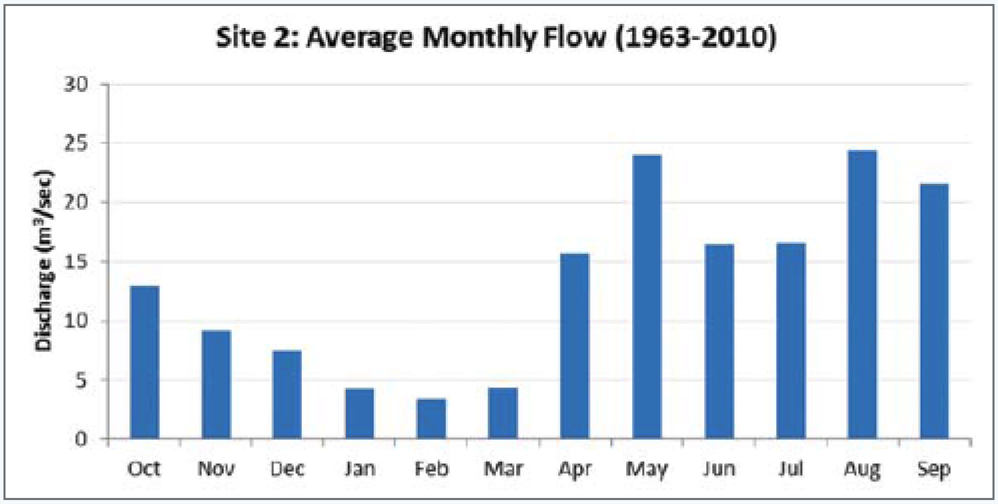
Appendix 2: EFA Participants (continued)

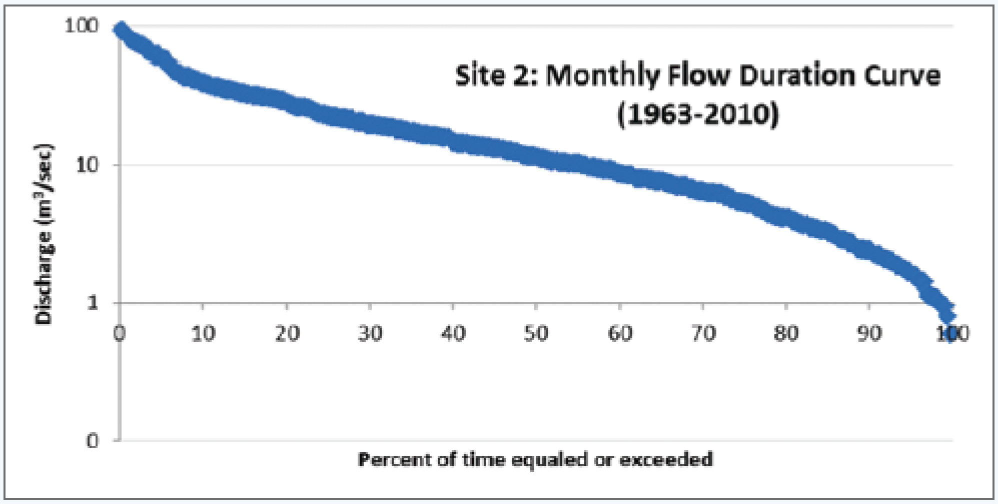
Participant Groups	Name and Role	Organization
EFA Team	Michael McClain, Water Quality Specialist, 2006-09	Florida International University, USA UNESCO-IHE, The Netherlands
	Mathayo Athuman, Water Quality Specialist, 2011-12	Lake Victoria Basin Water Office, Tanzania
	Joseph Ayieko, Riparian Vegetation Specialist, 2006-09	Egerton University, Kenya
	Cosmas Mligo, Riparian Vegetation Specialist, 2011-12	University of Dar es Salaam, Tanzania
	D. Victor Wasonga, Macroinvertebrate Specialist, 2006-09	National Museums of Kenya
	Rashid Tamatamah, Fish and Macroinvertebrate Specialist, 2006-12	University of Dar es Salaam, Tanzania
	Amanda Subalusky, Aquatic Ecologist and Research Associate, 2008-12	Florida International University, USA, Yale University, USA
	Christopher Dutton, Research Associate, 2008-12	Florida International University, USA, Yale University, USA
Workshop Facilitators	Doris Ombara Okundi, 2006-09	WWF-ESARPO, Mara River Basin Management Initiative
	Jay O'Keeffe, 2006-09	UNESCO IHE, The Netherlands
	Michael McClain, 2006-12	Florida International University, USA
	Elizabeth Anderson, 2011-12	Florida International University, USA

Appendix 3: Sampling site names and locations

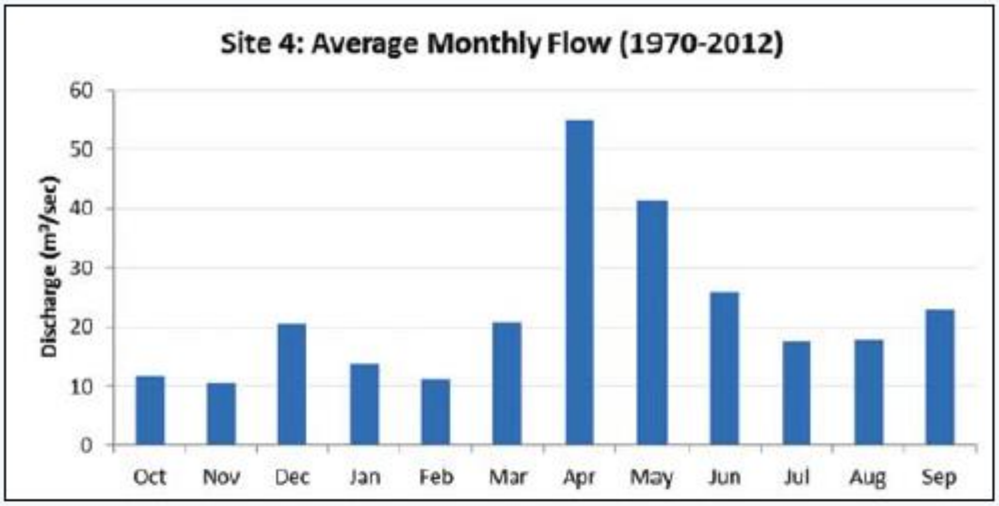
Site Name	Location	Site Coordinates		Site Coordinates
		Latitude	Longitude	
EFA 1	Amala River at Kapkimolwa	0°53'53.39"S	35°26'15.67"E	March 26-27, 2007, July 16-17, 2007 February 21, 2009
EFA 1.2	Nyangores River at Silibwet	0°59'21.84"S	35°15'37.83"E	February 22, 2009
EFA 2	Mara River at Mara Safari Club	1° 5'33.11"S	35°11'48.35"E	March 28-29, 2007, July 18-19, 2007 February 23, 2009
EFA 3	Mara River at Kenya-Tanzania Border	1°33'3.56"S	35° 1'1.25"E	March 30-31, 2007, July 20-21, 2007 February 24, 2009
EFA 4	Mara River at Kogatende	1°33'13.83"S	34°51'24.63"E	9-10 February, 2012 10-12 May, 2012
EFA 5	Mara River at Mara Mine	1°32'47.45"S	34°33'14.73"E	7-8 February, 2012 8-9 May, 2012

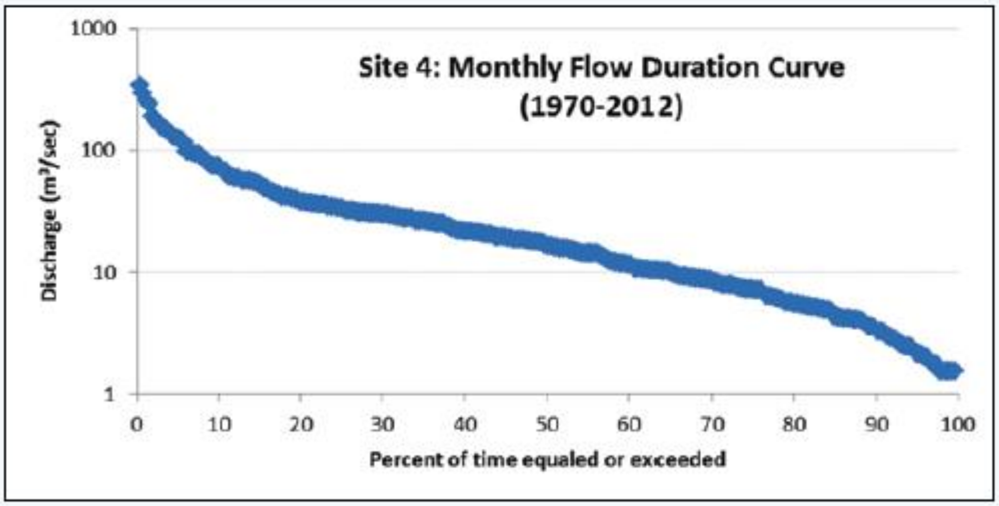
Appendix 4: Historical discharge information for EFA Site 2





Appendix 5: Historical discharge information for EFA Site 4





Global Water for Sustainability Program
Florida International University
Biscayne Bay Campus
3000 NE 151St. ACI-267
North Miami, FL 33181
Phone: (+1-305) 919-4112
Fax: (+1-305) 919-4117
www.globalwaters.net



Printed on recycled paper.